

Studying the spin structure of the proton at PHENIX

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for the PHENIX collaboration
Circum-Pan-Pacific Symposium
September 15, 2009
Yamagata, Japan

RHIC-PHENIX introduction

RHIC:

The polarized p+p collider

High energy (\sqrt{s} is up to 500GeV)

Longitudinal and transverse with the spin rotator

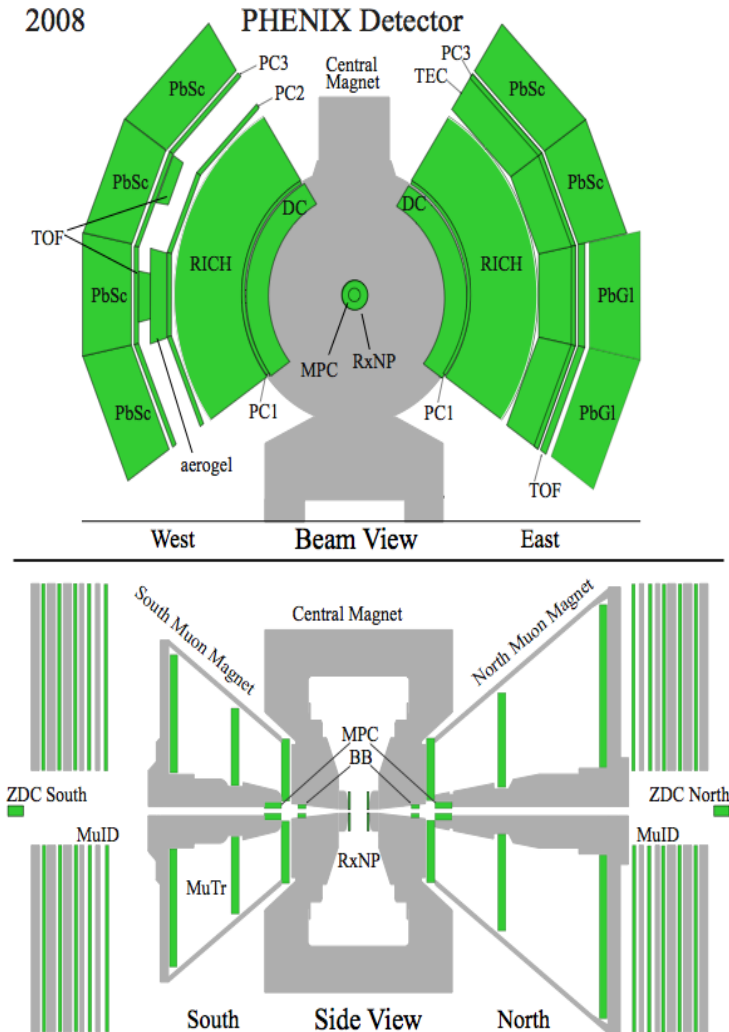
PHENIX:

Central arm ($|\eta| < 0.35$)

Forward muon arm ($1.2 < |\eta| < 2.4$)

MPC (=Forward EMCAL) ($3.1 < |\eta| < 3.9$)

Particle ID, Trigger, fast DAQ system



Spin Physics at PHENIX

3 main topics and others

- Gluon component (ΔG program)
 - Anti-quark flavor decomposition (W at $\sqrt{s}=500\text{GeV}$)
 - Transverse spin structure
- +Others
-

In this talk

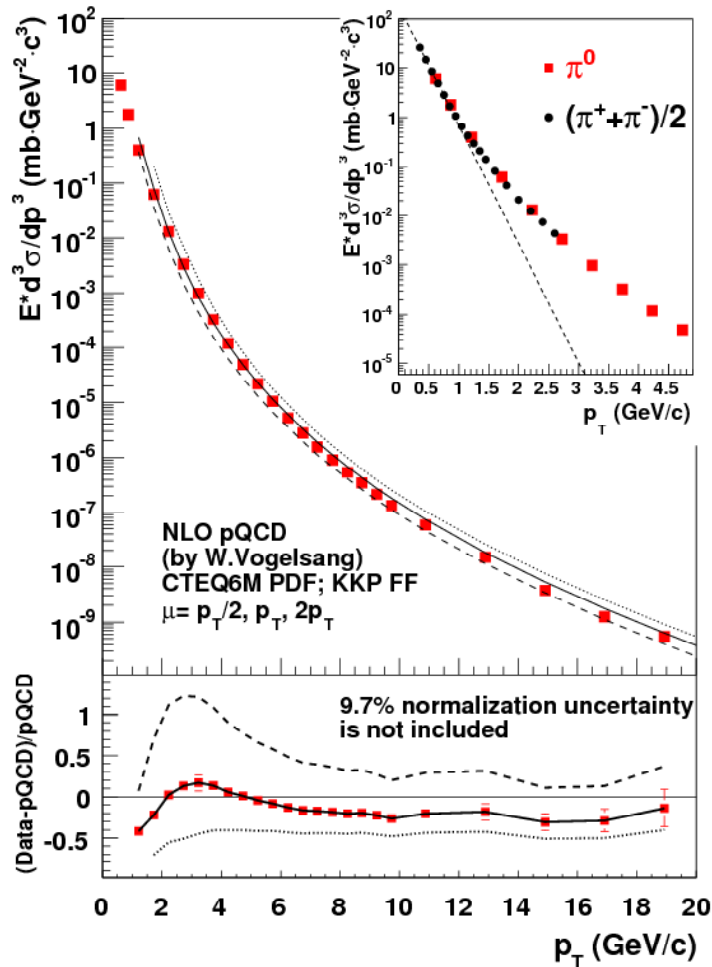
Results

Next steps

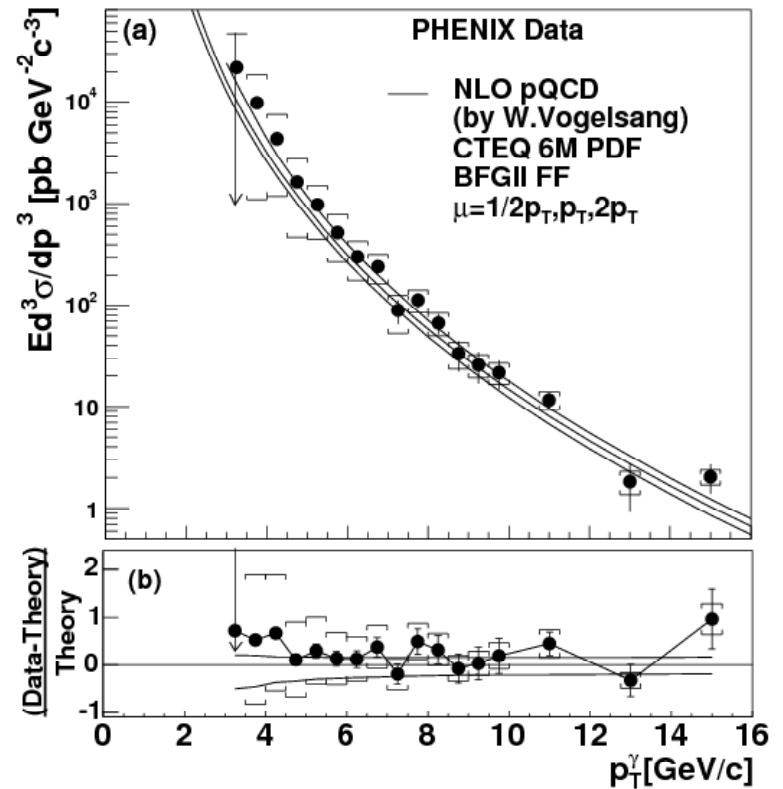
Cross section measurements

$pp \rightarrow \pi^0 X$:
PRD76,051106

$\sqrt{s}=200\text{GeV}$
Mid rapidity ($|\eta| < 0.35$)



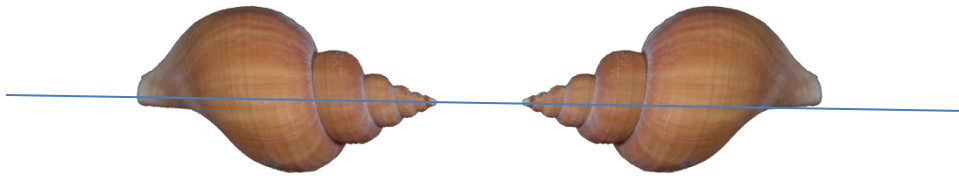
$pp \rightarrow \gamma X$:
PRL 98, 012002



And also eta, h^\pm , single electron (from charm)
pQCD calculations consistent with all measurements

pQCD our theory baseline is OK!

Longitudinal spin structure

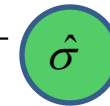


(Gluon component)

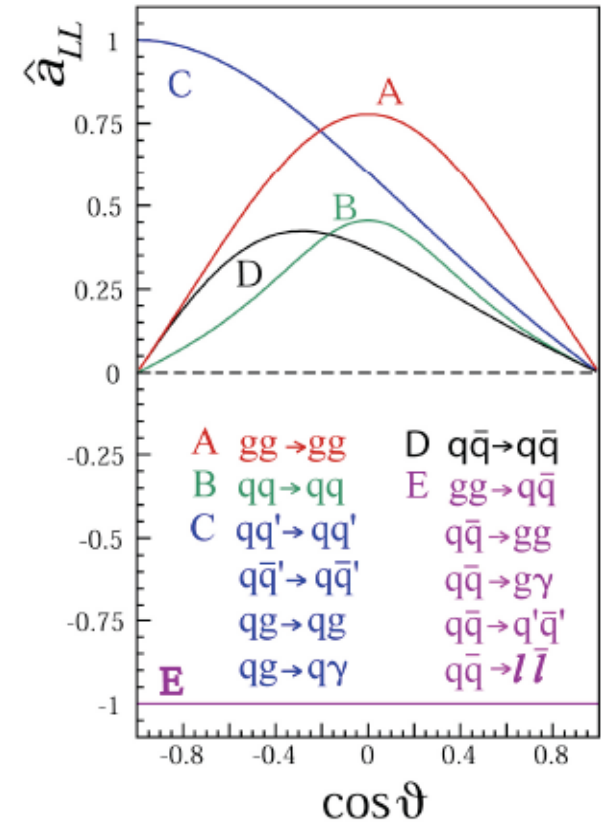
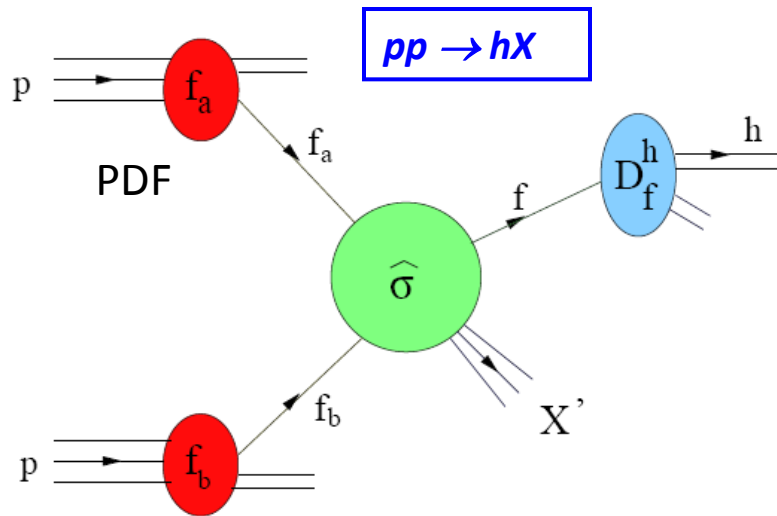
Probing ΔG

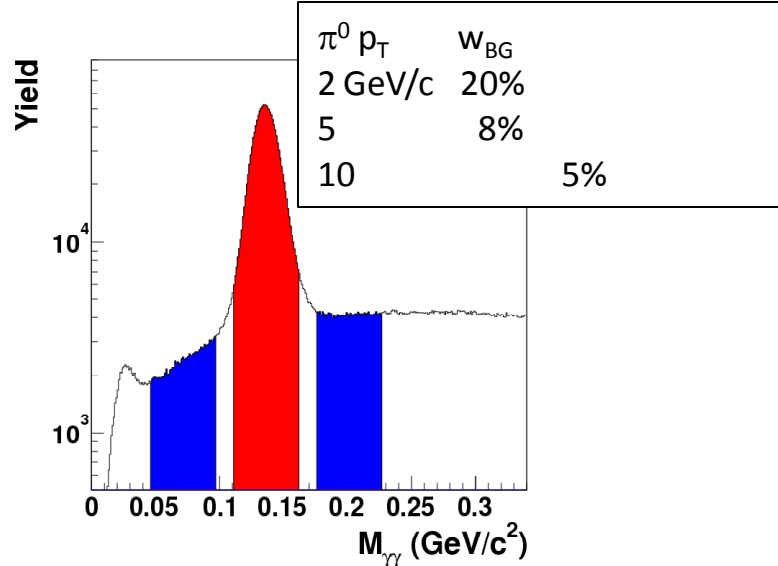
Double longitudinal spin asymmetry (A_{LL}) is sensitive to ΔG

$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \rightarrow fX} \cdot \hat{a}_{LL}^{f_a f_b \rightarrow fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \rightarrow fX} \otimes D_f^h}$$

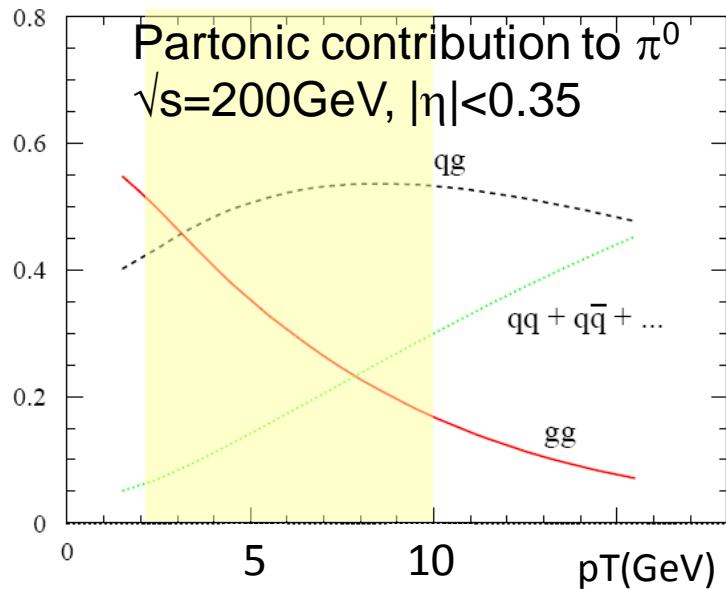


Spin dependence





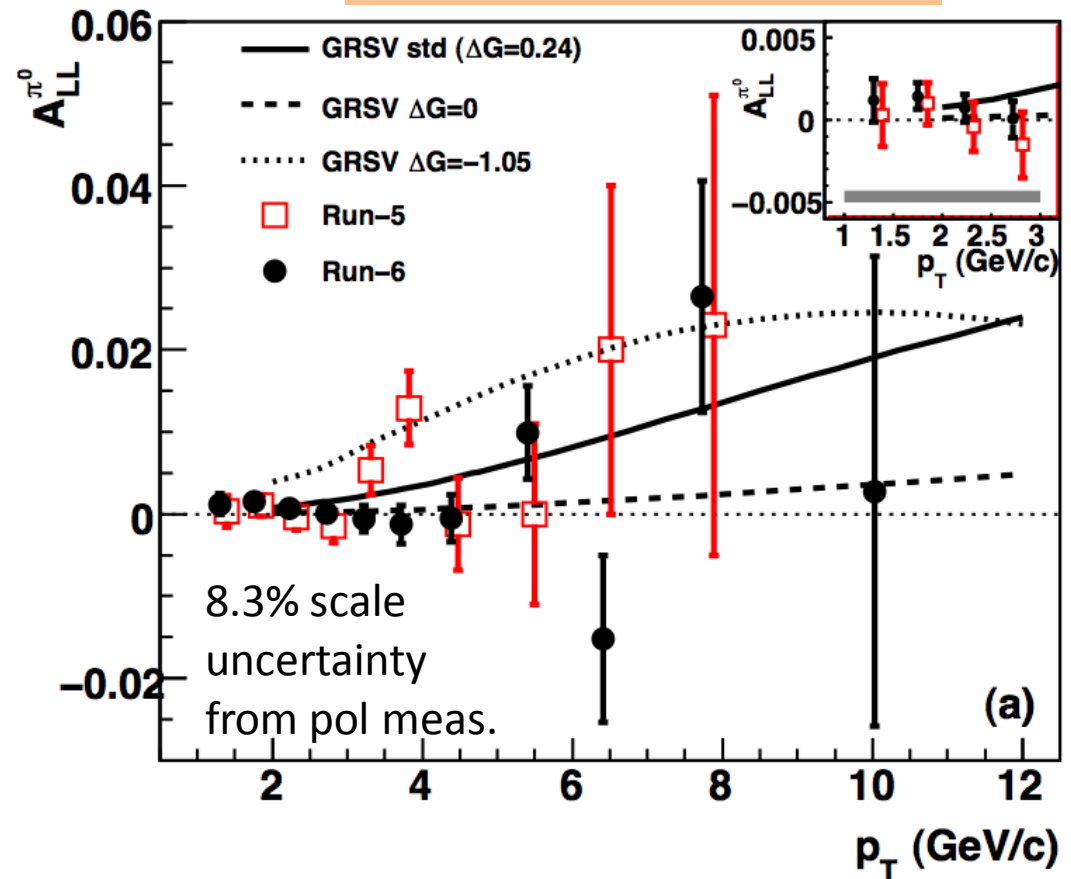
$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$



$\pi^0 A_{LL}$

The most abundant probe in PHENIX
 (triggering + identification capability)

PRL 103,012003(2009)

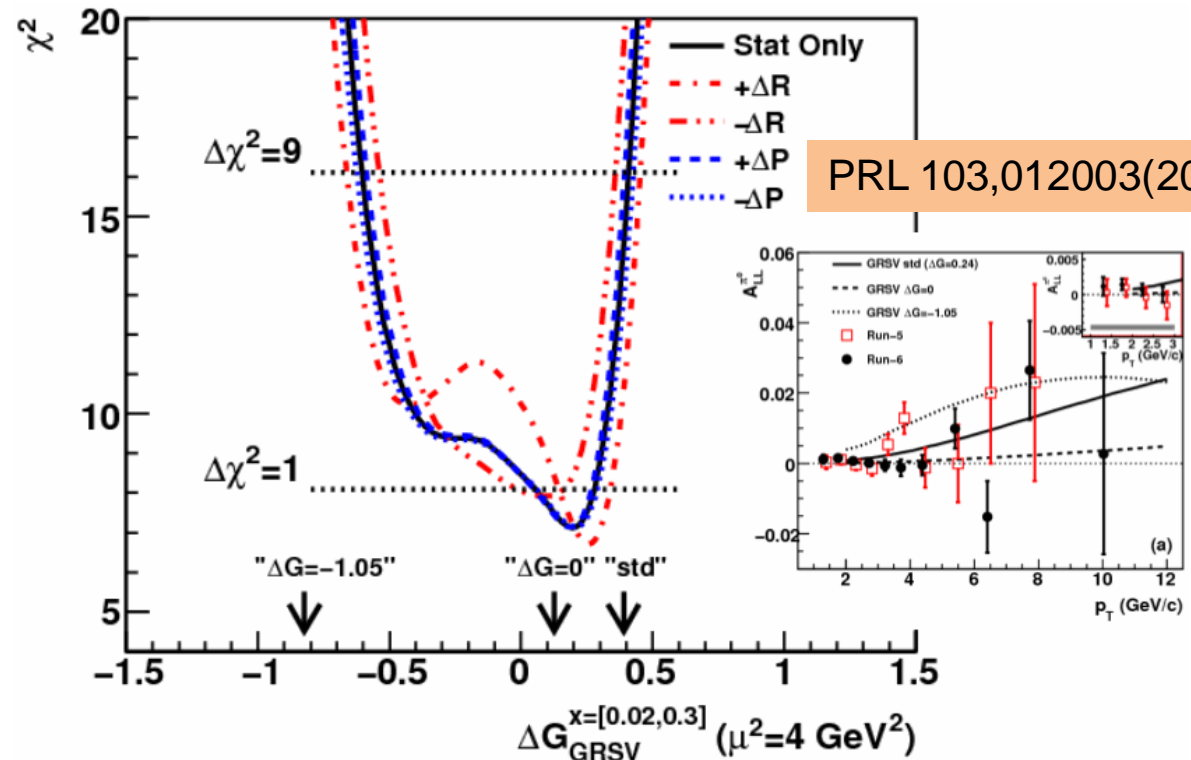
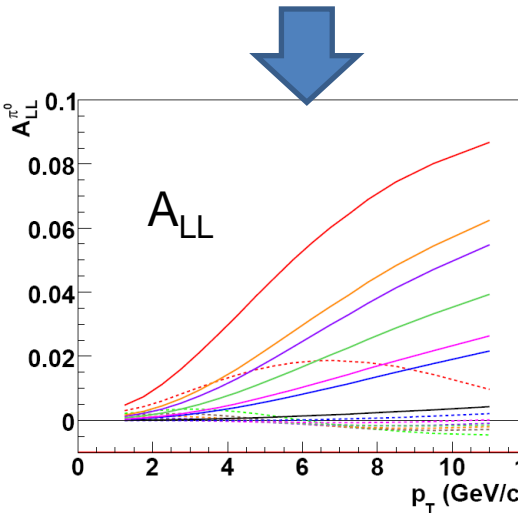
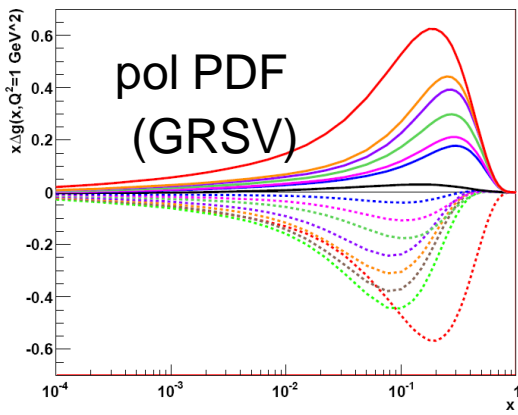


From A_{LL} to ΔG (with GRSV model)

Generate $\Delta g(x)$ curves for different $\Delta G = \int_0^1 g(x) dx$ (with DIS refit)

Calculate A_{LL} for each ΔG

Compare A_{LL} data to curves (produce χ^2 vs ΔG)

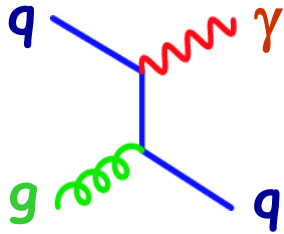


Stat. error : $\Delta G_{GRSV}^{x=[0.02,0.3]} (\mu^2 = 4 \text{ GeV}^2) = 0.2 \pm 0.1 (1\sigma)$ and $0.2^{+0.2}_{-0.8} (3\sigma)$

Syst. exp. error : ± 0.1

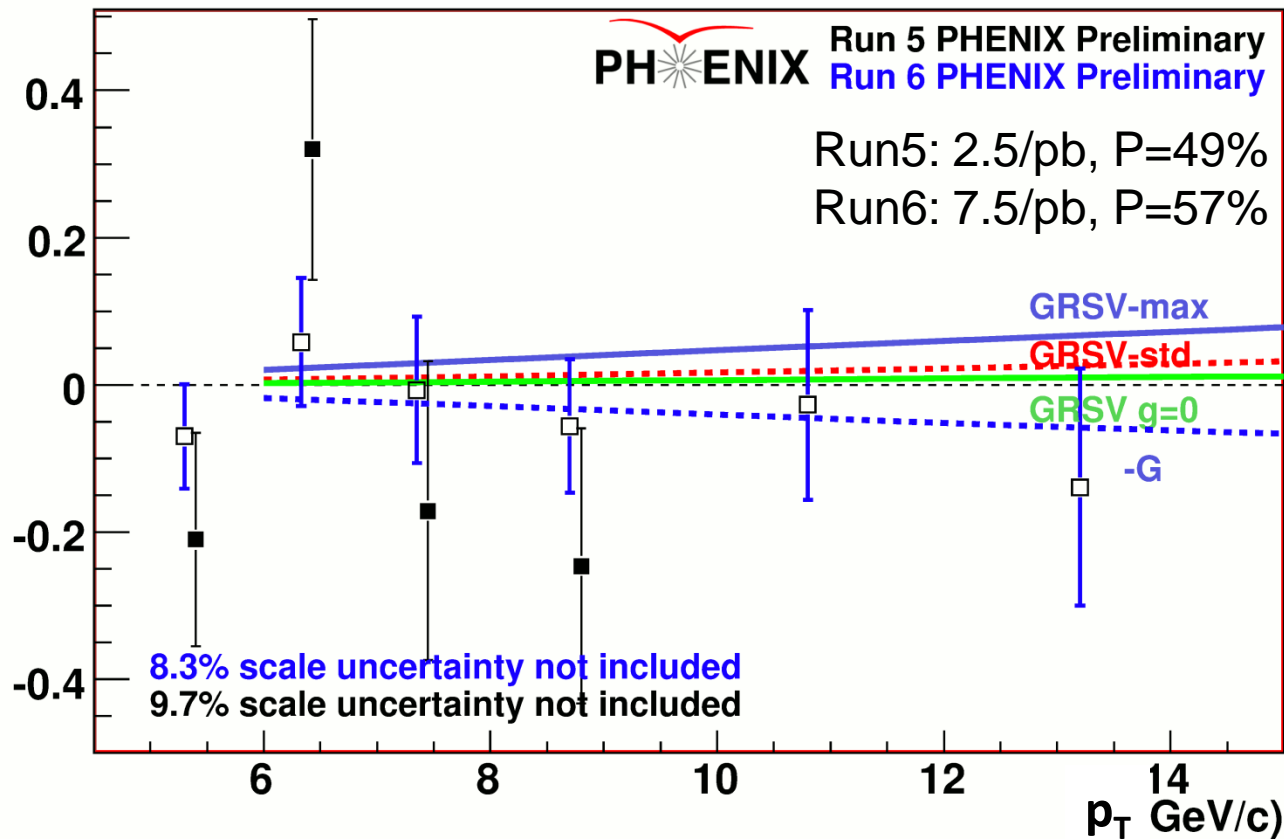
The gluon contribution is not large.

Direct photon A_{LL}



clean channel
sensitive to the sign of ΔG

$A_{LL}(\text{Direct-}\gamma)$



Statistically limited.

Better S/N in
high p_T

Other probes to access ΔG

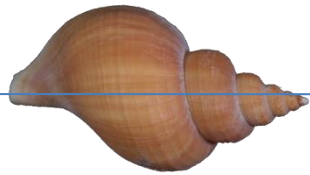
charged pions : u,d quark difference

eta : an additional information

heavy flavor : the gluon fusion process, via electron/muon

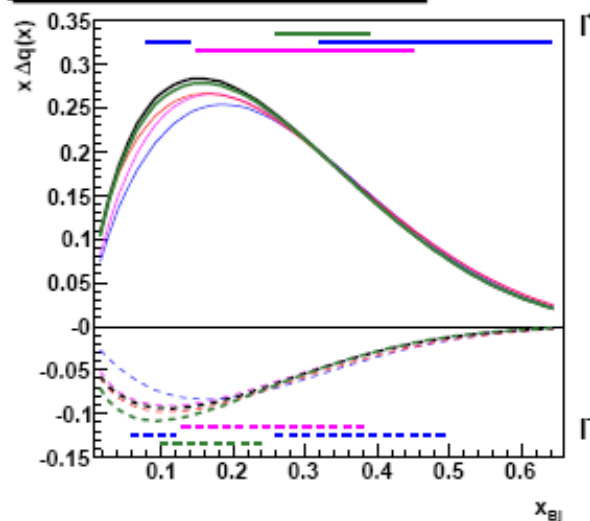
Jet : higher p_T reach, different systematic

Anti-quark flavor decomposition

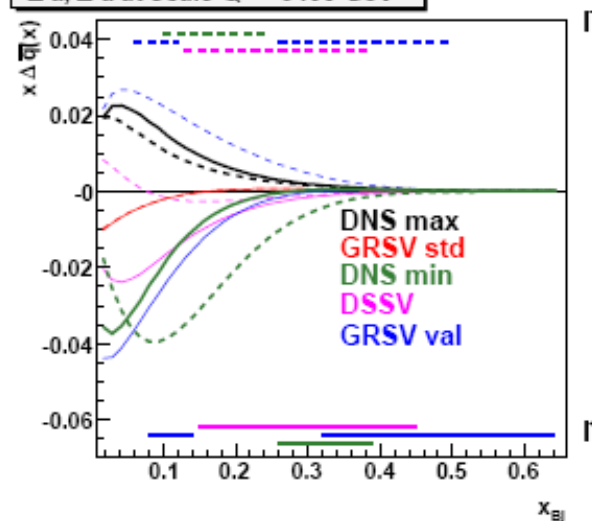


(anti) quark components

$\Delta u, \Delta d$ at scale $Q^2 = 6400 \text{ GeV}^2$



$\Delta \bar{u}, \Delta \bar{d}$ at scale $Q^2 = 6400 \text{ GeV}^2$



From SIDIS

W program at RHIC

$$\bar{d} + u \rightarrow W^+$$

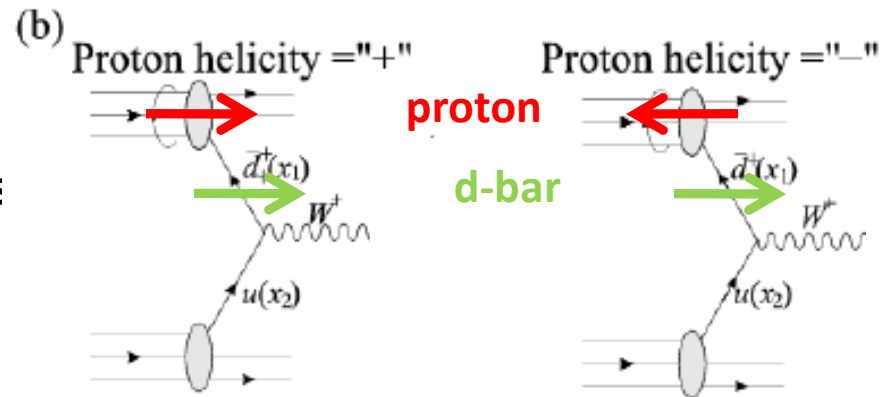
$$\bar{u} + d \rightarrow W^-$$

**\bar{d} , \bar{u} is always
positive helicity**

W^+ A_L : Longitudinal single spin asymmetry
information of \bar{d} in the proton

No fragmentation function needed.

Test at very high Q^2 ($M_W^2 = 6400 \text{ GeV}^2$)



2009 (Run9) run

Period : February – July

Collision : pp500GeV and pp200GeV

The first 500GeV pol p+p data

~10 pb⁻¹ is accumulated for the central arm W signal.

Polarization is preserved to the top energy.

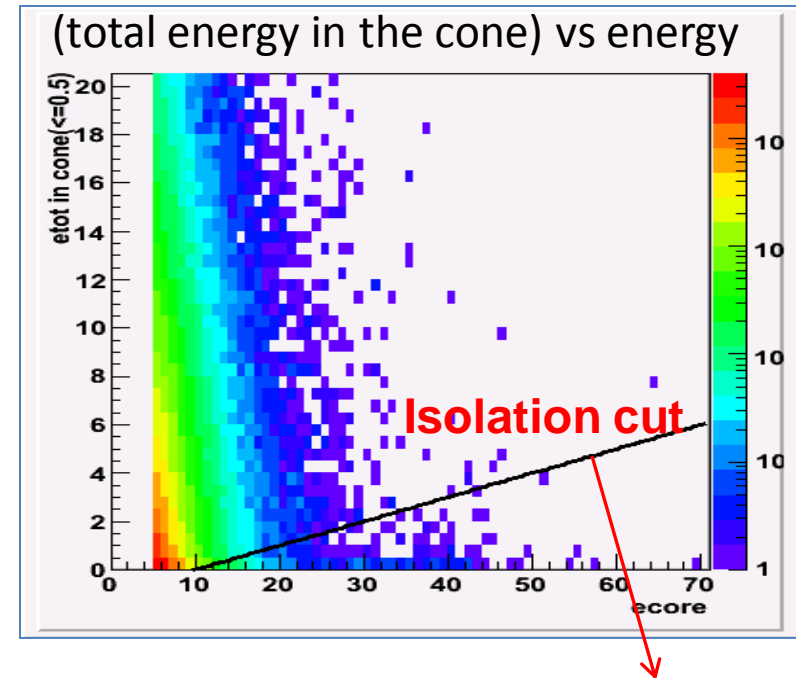
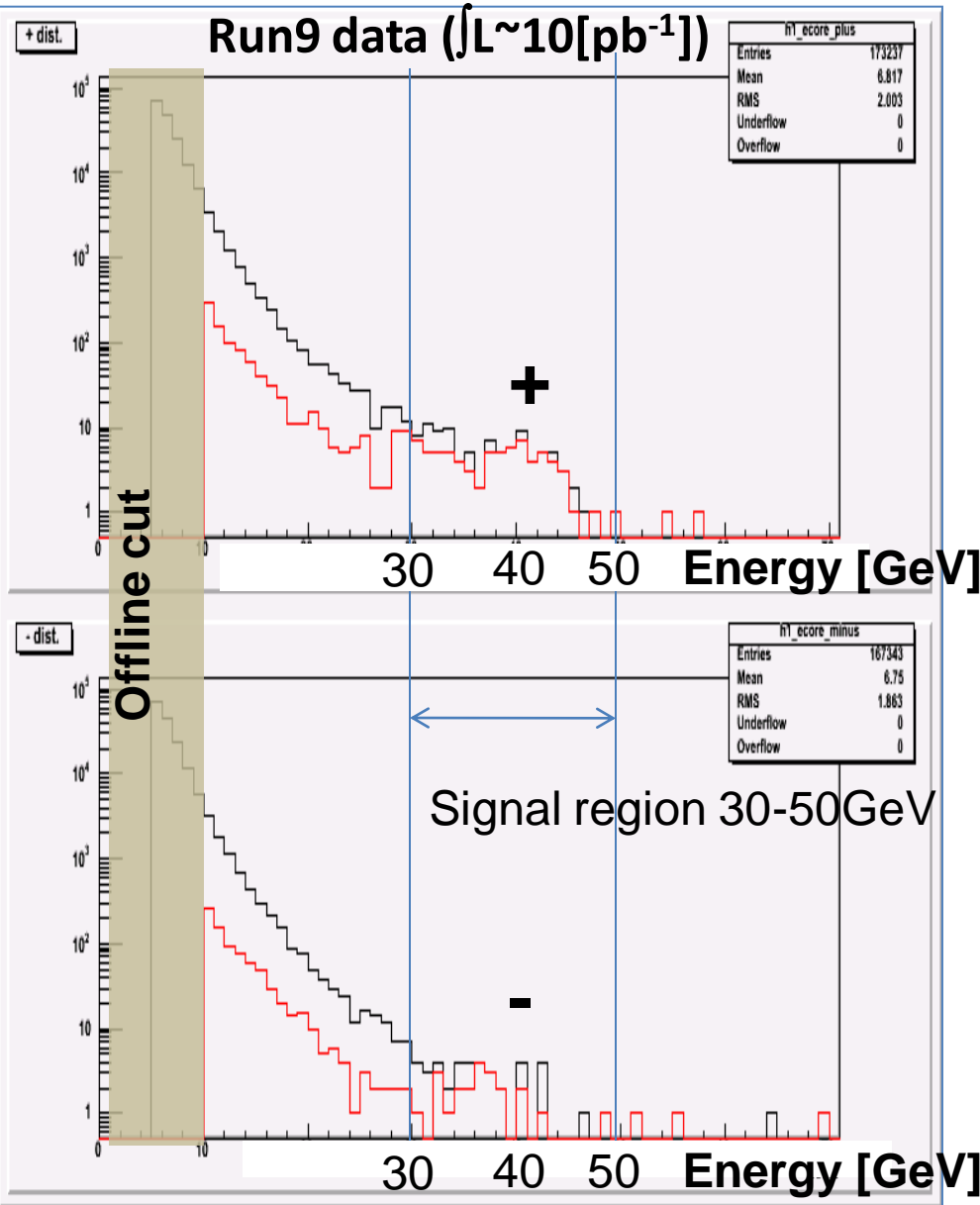
W to Electron channel :

with the central arm, signal confirmation.

W to Muon channel:

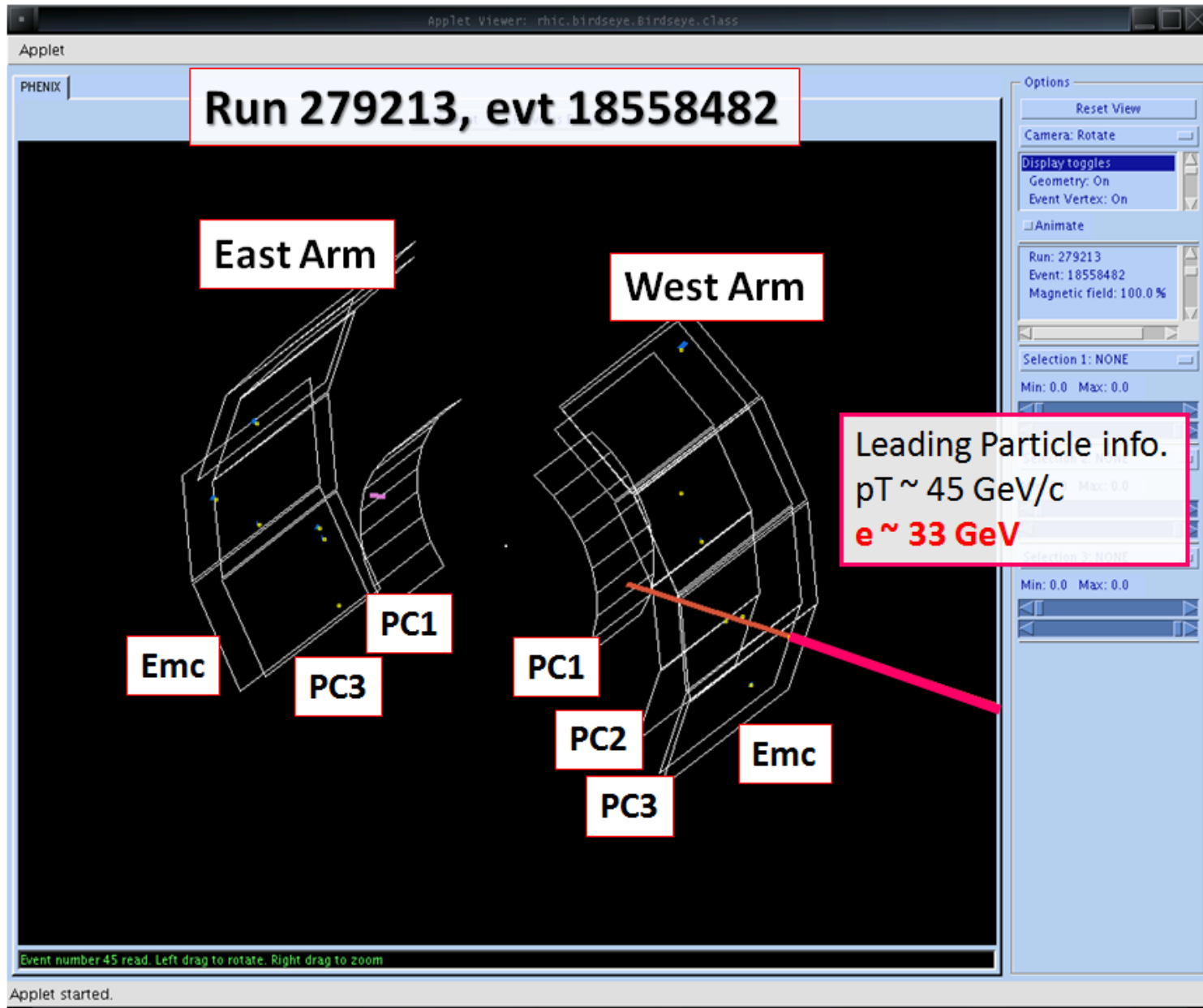
with the muon arm, trigger upgrade commissioning.

W→electron signal

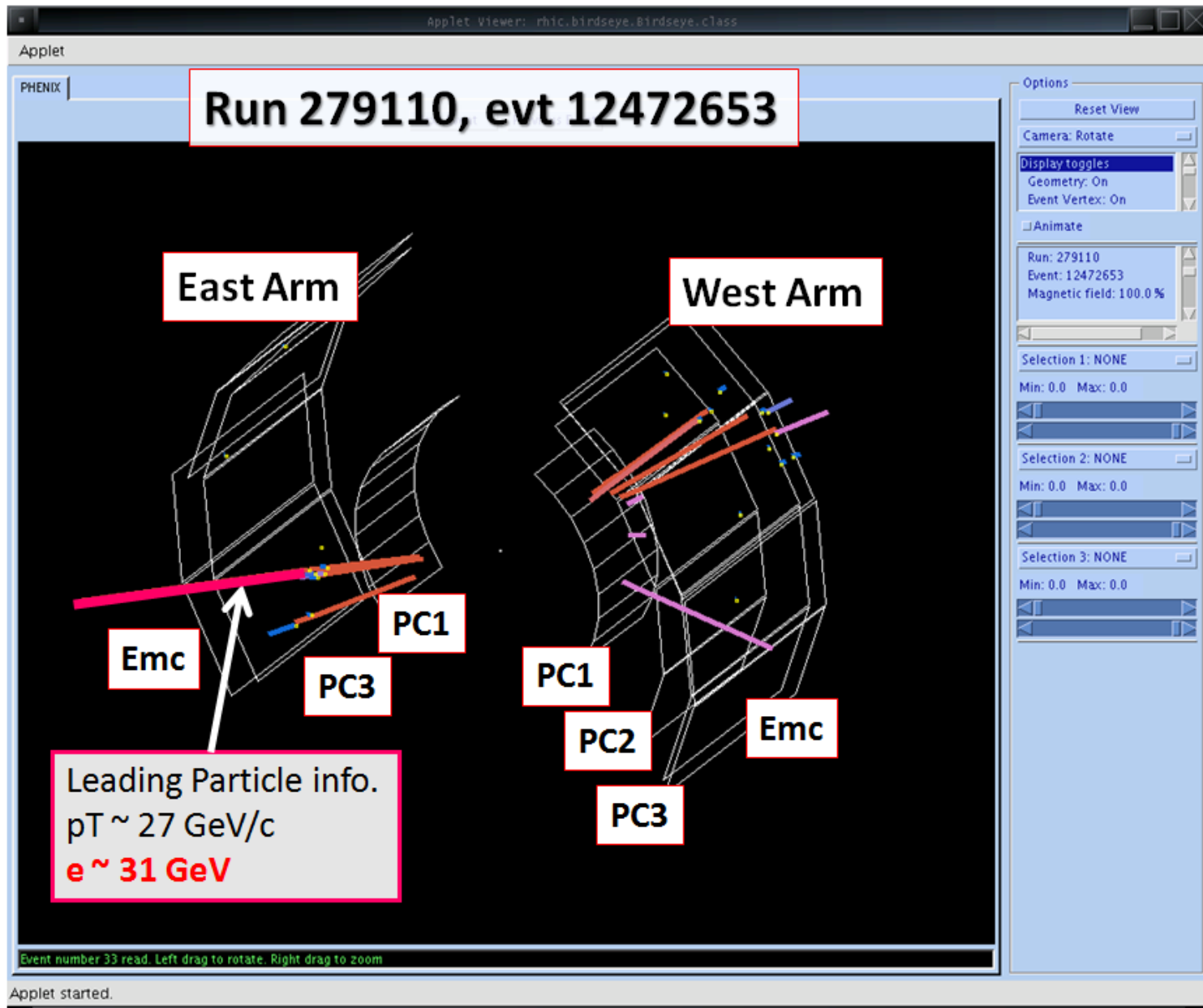


Cone size = 0.5,
 Energy total =
 EMCal energy + track momentum

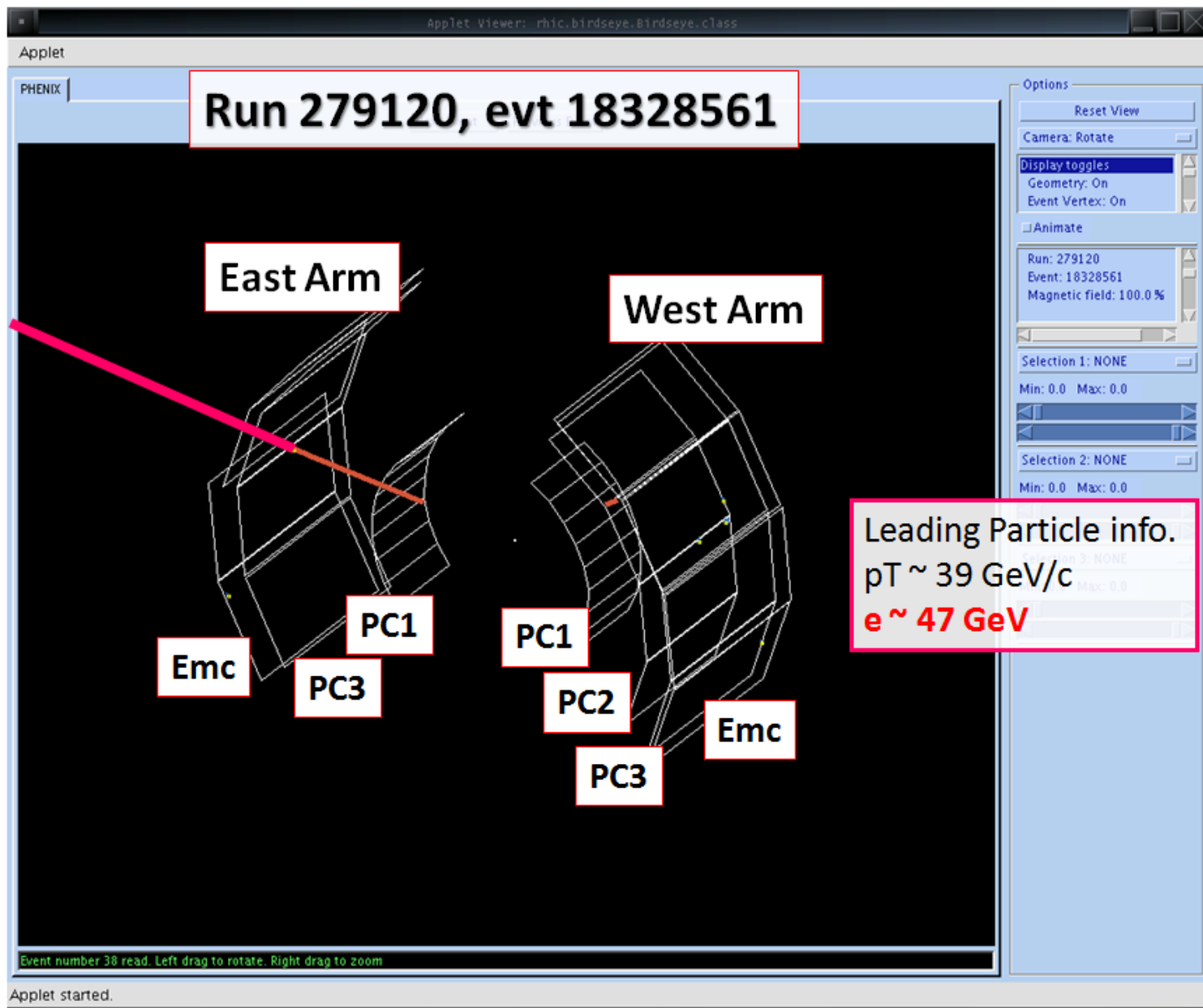
Event display



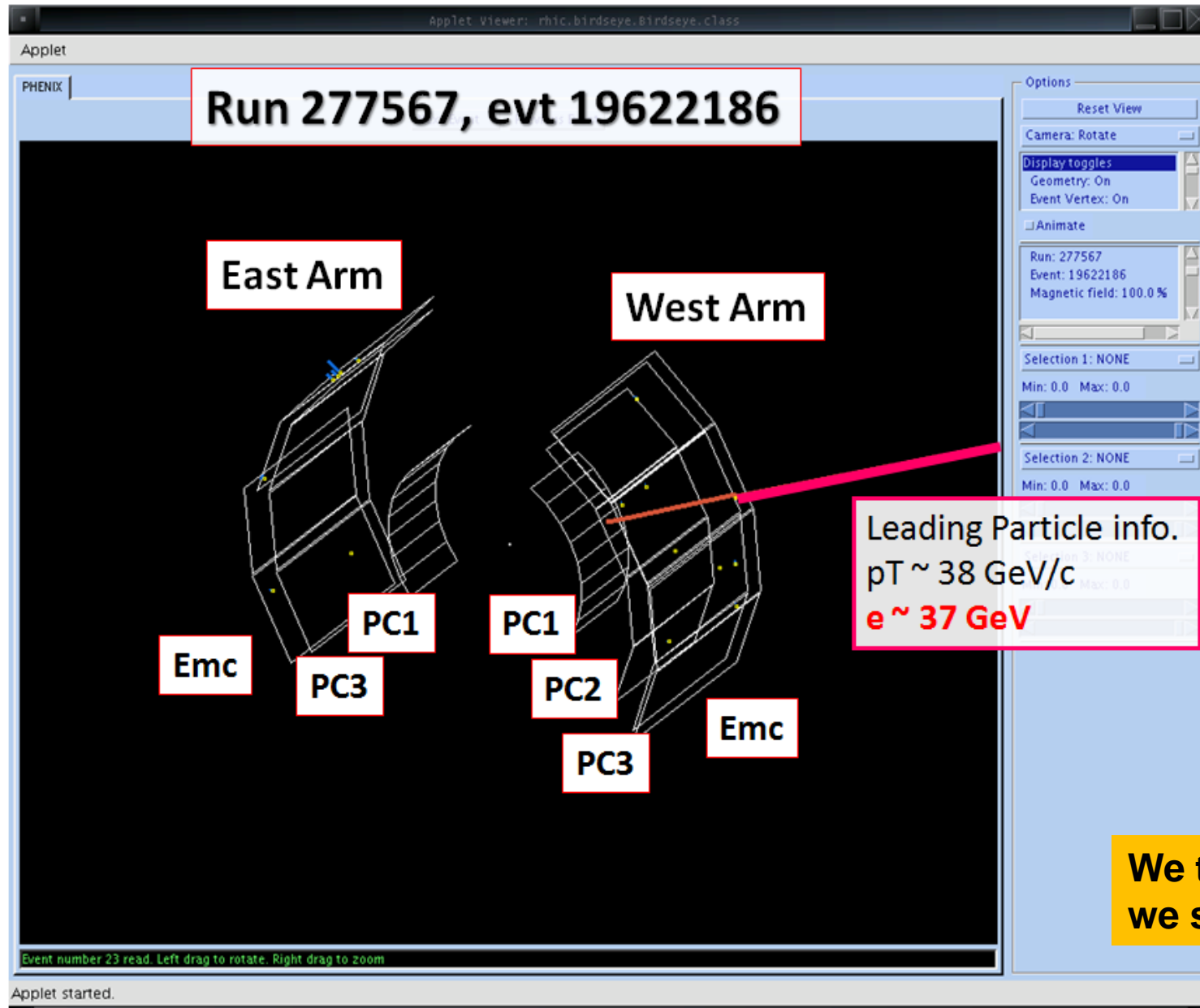
Event display 2/4



Event display 3/4



Event display 4/4



We think
we see W signals!

Transverse spin structure

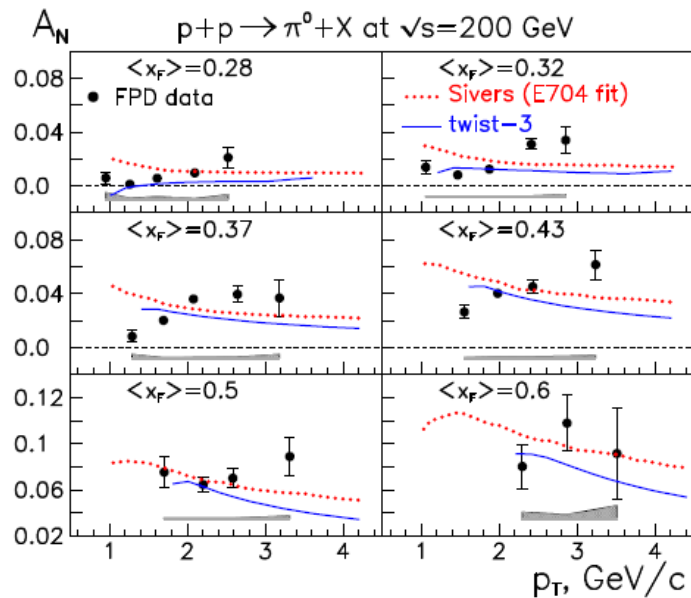
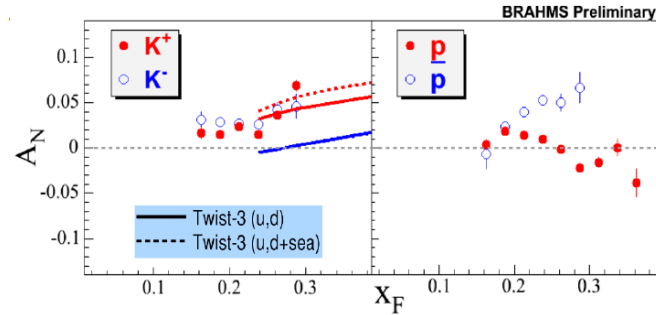
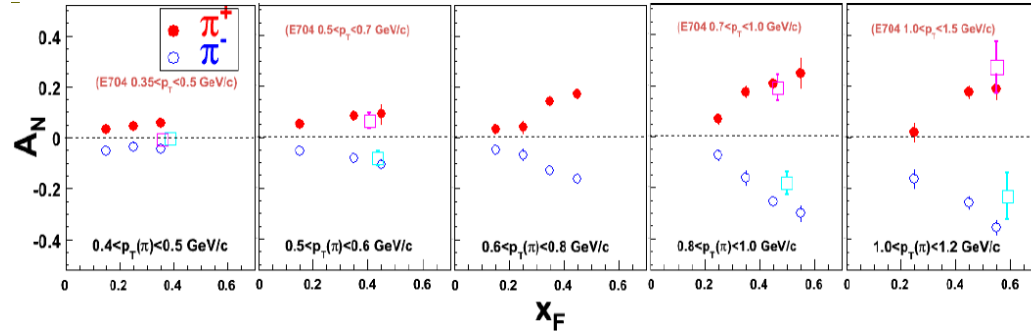


The current situation

It's a hot topic in the world.

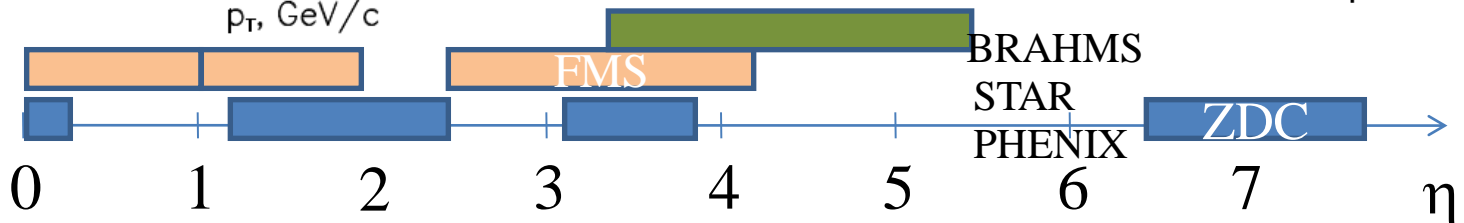
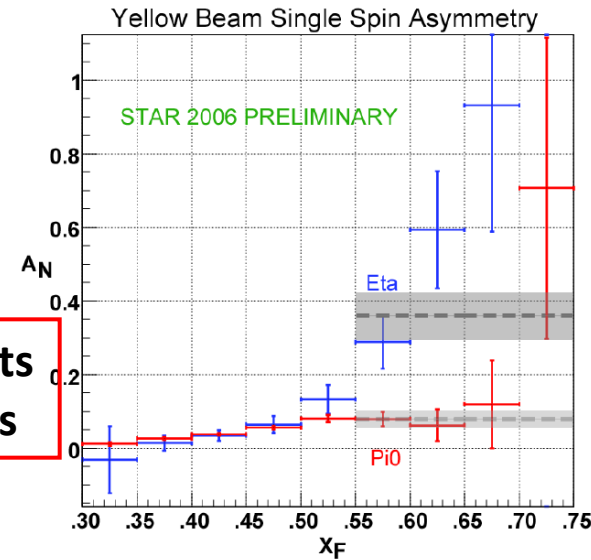
At SIDIS, COMPASS and HERMES disagree on Sivers asymmetry measurements.

At RHIC, there are measurements where the mechanism is not well understood.

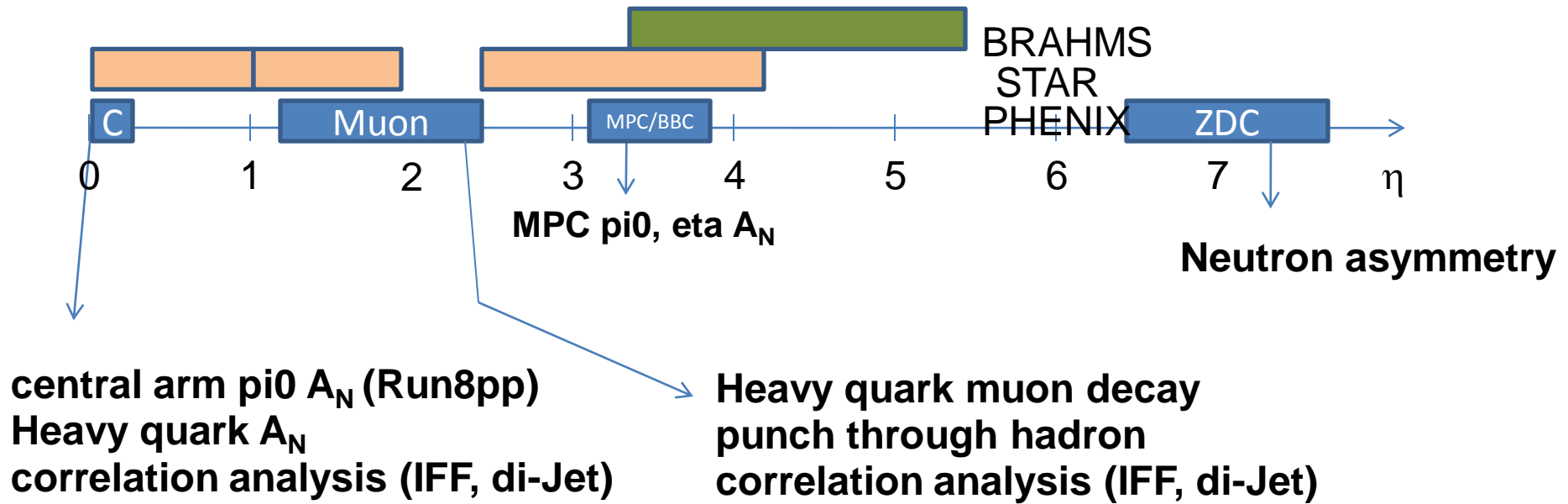


Particle dependence?
No \sqrt{s} dependence?
 A_N p_T dependence?
di jet k_T asymmetry cancel?

Complementary measurements
will disentangle various effects

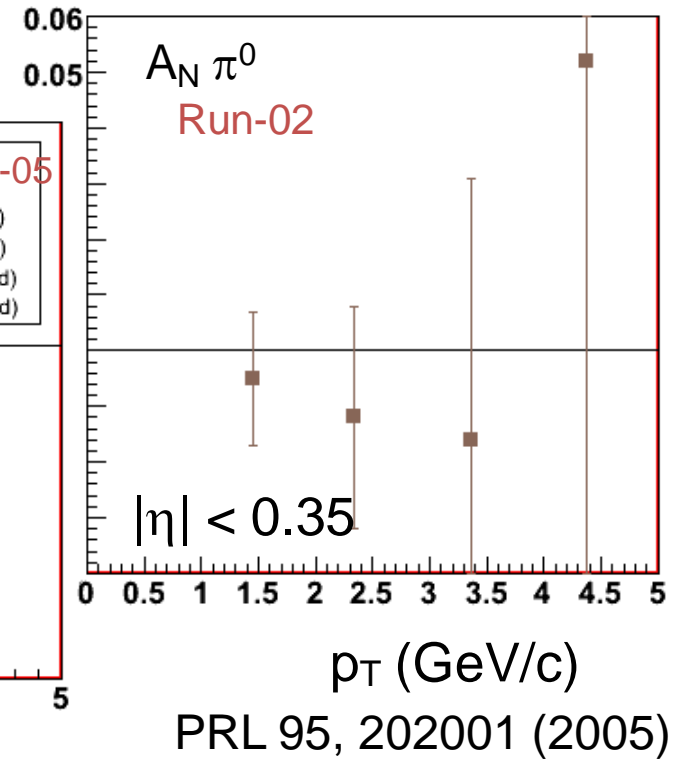
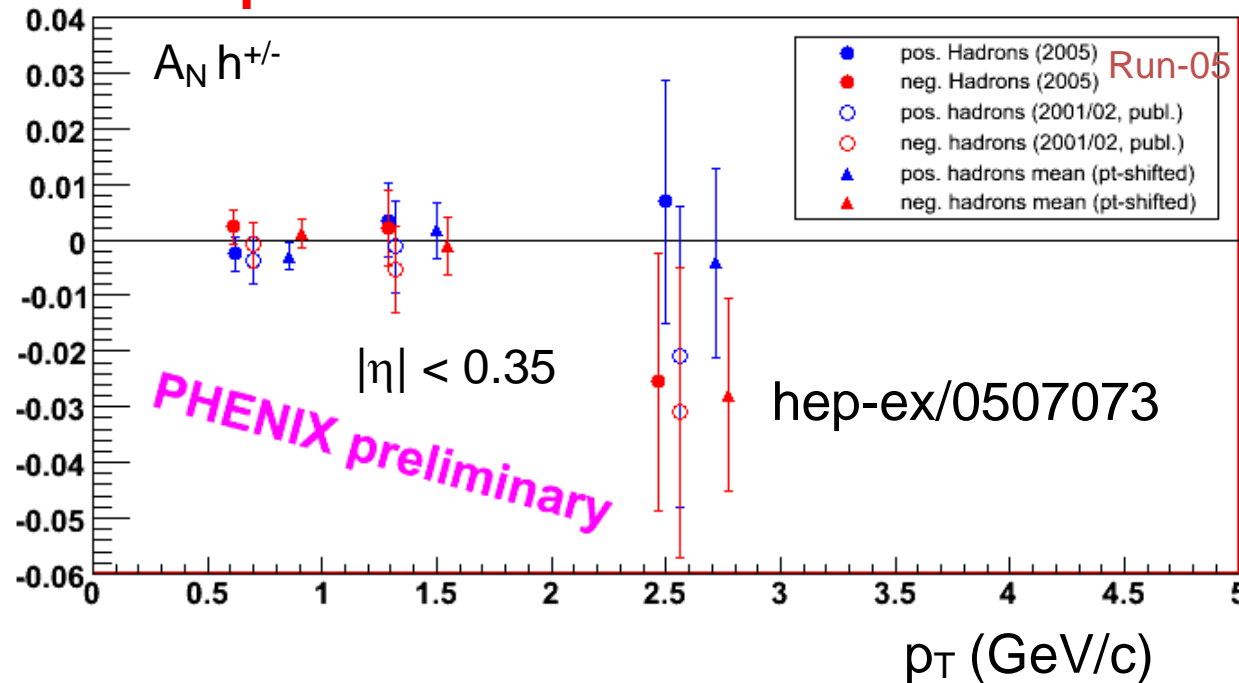
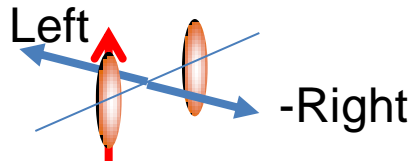


PHENIX single spin analysis catalogue



Central-forward correlation

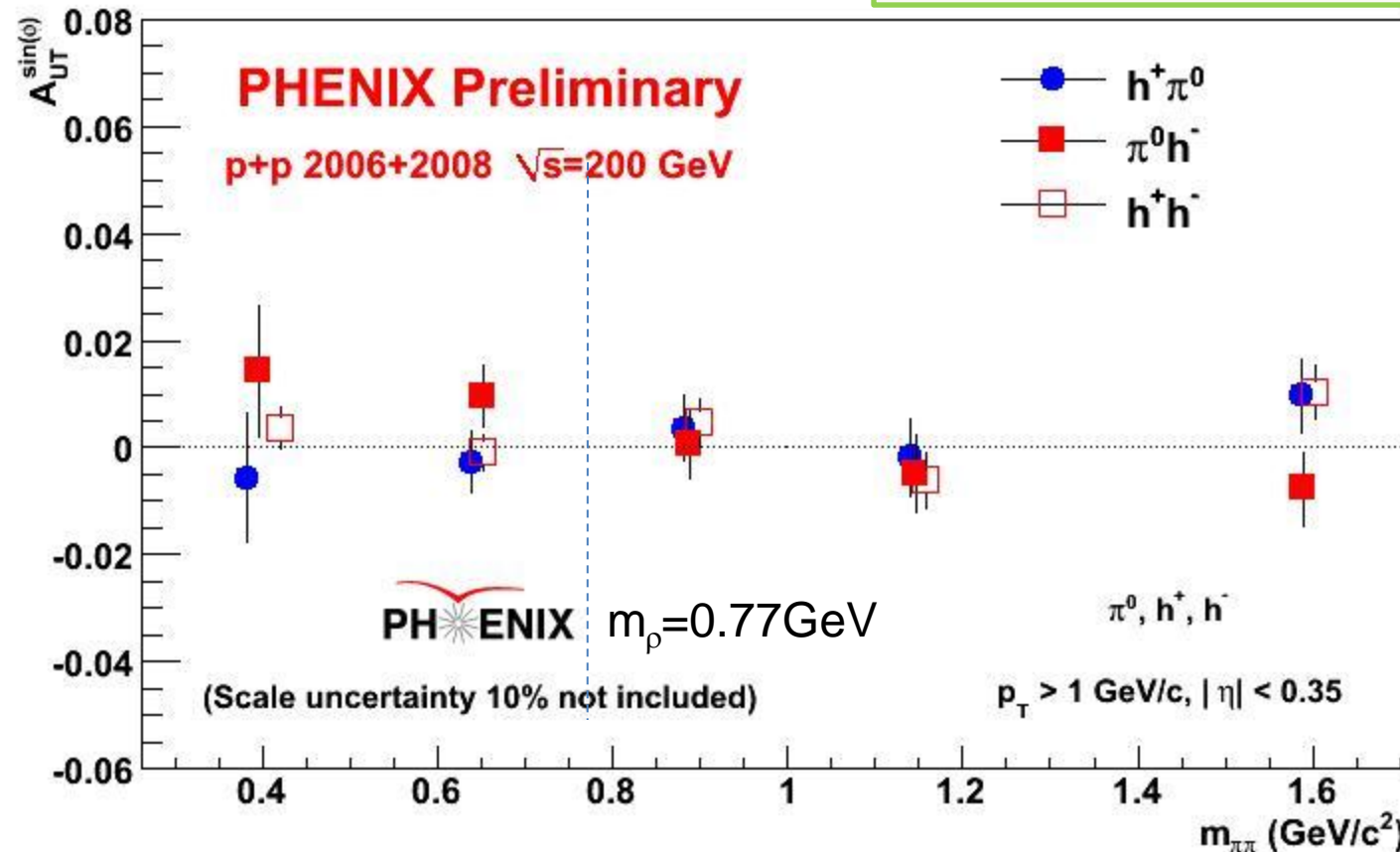
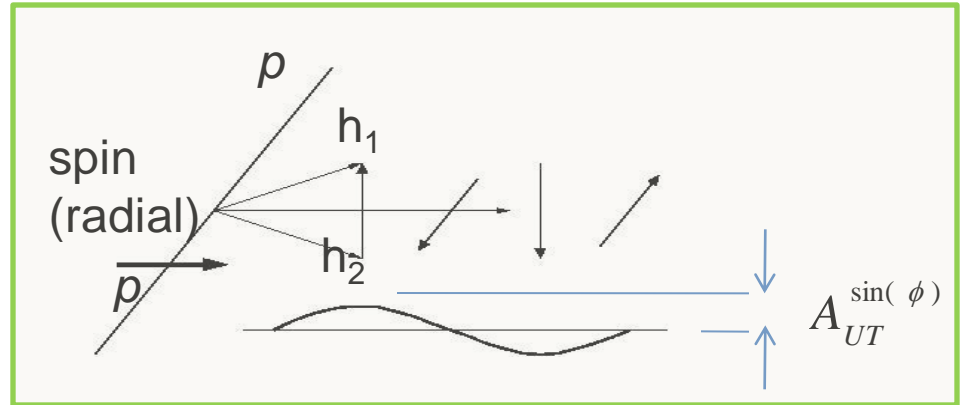
Midrapidity hadron A_N



- A_N is zero within 1%
- It constrains Sivers distribution function for gluons.
(Anselmino et al., PRD74, 094011 (2006))
- Updated π^0 result (with $>10\times$ smaller stat. uncertainty) is coming.

Interference FF as an analyzer

Transversity *IFF
2 hadrons in the central arm.



It's consistent with zero within the statistical uncertainty.

Non zero IFF is reported from BELLE at Dubna (Sep.2009).

A trend exists?

The transversity will be constrained.

Muon arm analysis is on going.

Others related to the spin



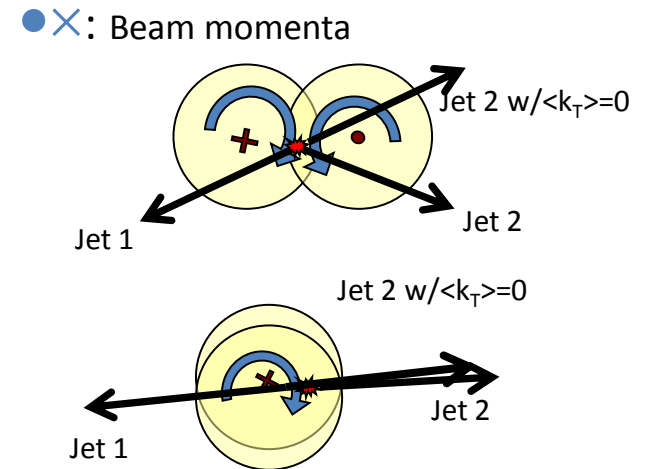
Others related to the spin

Very forward ($<\pm 2\text{mrad}$) neutron single spin asymmetry ... non-zero!

Jet k_T asymmetry new data (run5+6)
(a probe of quark orbital angular momentum?)

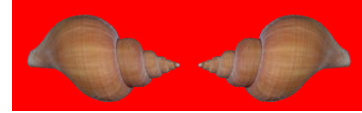
Spin transfer analysis
with self-analyzing decay channel (Λ)
Access to strange quark components?
It can be a good tool. But no good trigger.

Can J/Ψ be an analyzer?



Where are we going with PHENIX?

What's next in the ΔG program?

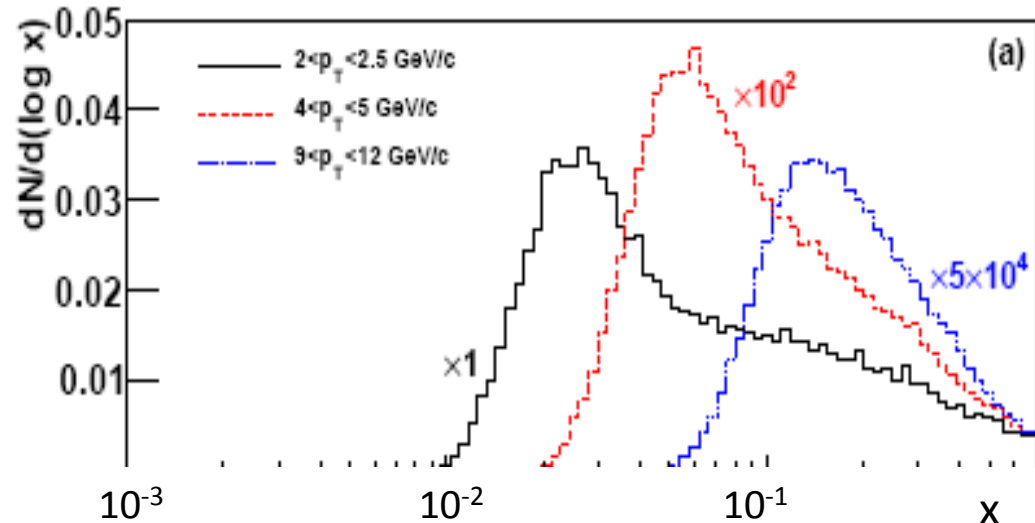
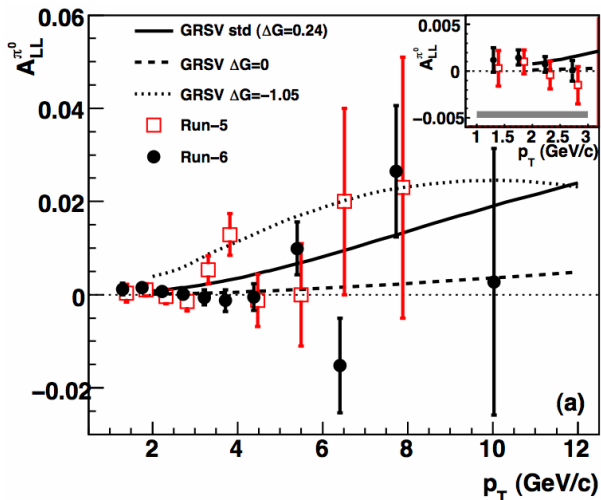


What's the sign of ΔG ? Does ΔG have a node?

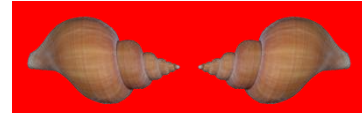
→ In general, what is the x dependence?

Direct photon $A_{LL}^{\pi^0}$: needs more data

Inclusive measurements have poor resolution in the x range.



ΔG : The next step



Negative ΔG constraint and x dependence

— Multi particle measurement

Mapping x by using away side particles.
(VTX detector will help.)

— Inclusive measurement

Direct photon, charged pions with high FOM ($x \sim 100$)

$\sqrt{s} = 500 \text{ GeV}$ small- x . Along with the W-program.

Lower \sqrt{s} for large x . If pQCD is applicable.

Forward region for small- x .

What's next in anti-quark flavor decomposition?



3 steps

1. Confirm our W decay signal. ($\sim \int L = 10/\text{pb}$)
2. Confirm non zero asymmetry from quark pol. ($\sim \int L = 100/\text{pb}$)
3. Constrain anti quark polarization. ($\sim \int L = 300/\text{pb}$)

For the $W \rightarrow \text{electron}$ channel, PHENIX is at step 1 with 2009 data.
For the $W \rightarrow \text{muon}$ channel, new trigger system is required.

Central $W \rightarrow e$ channel

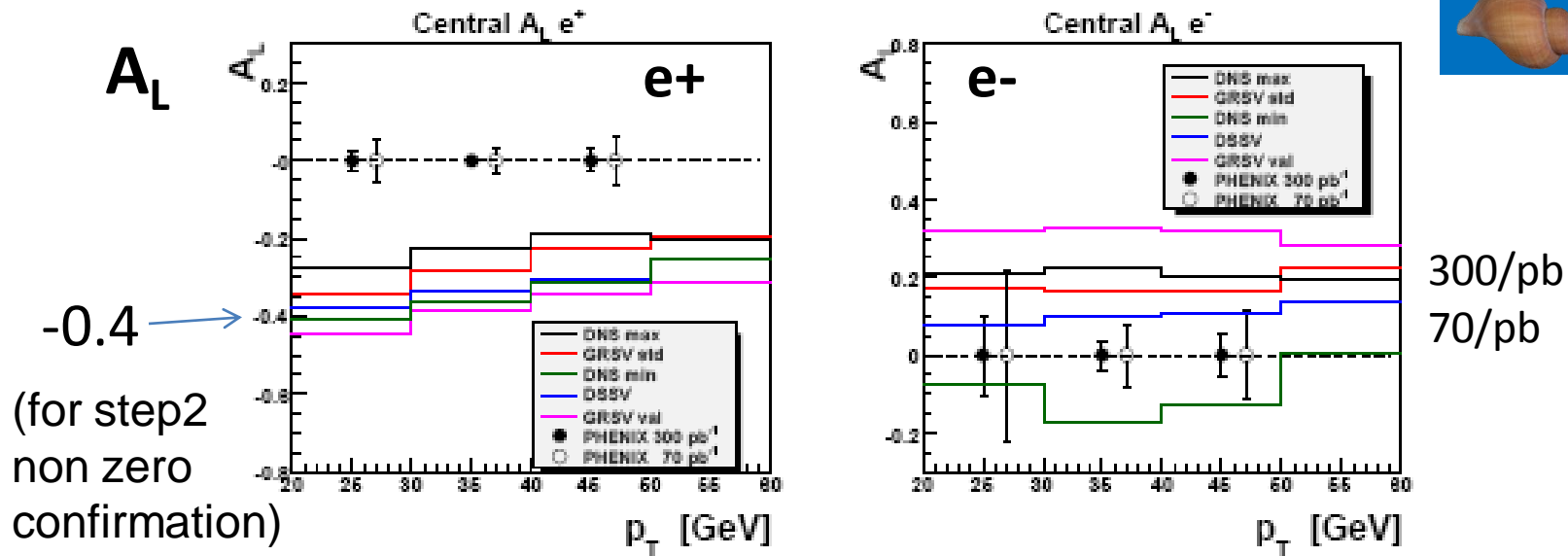
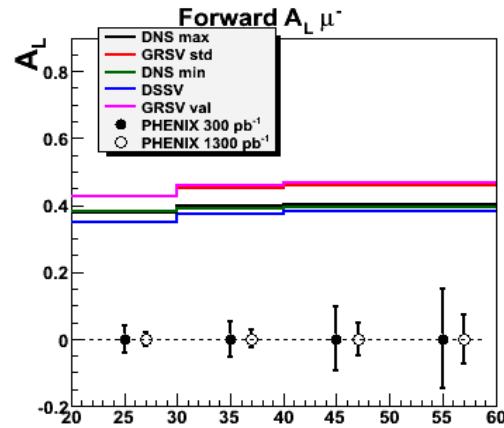
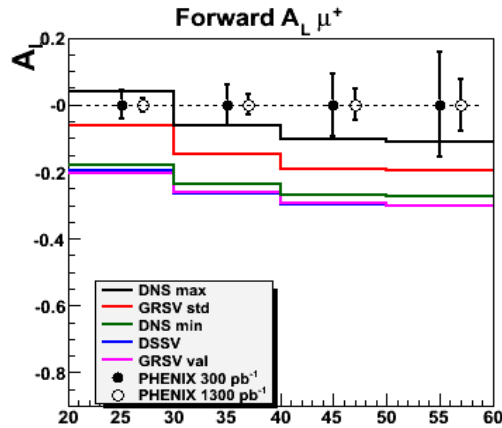
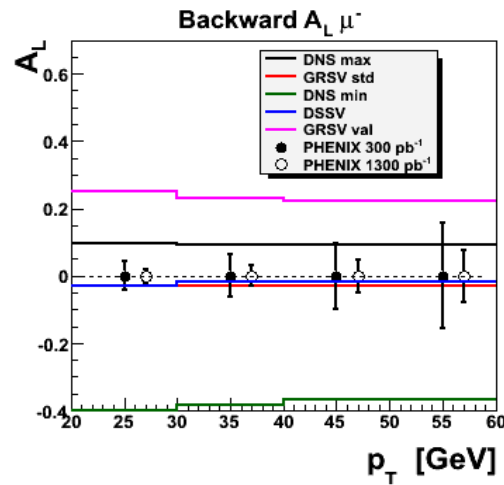
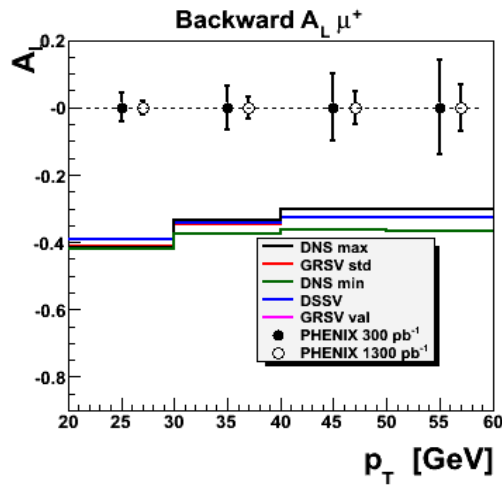


Figure 17: Simulated asymmetries in the PHENIX central arms for $W^+ \rightarrow e^+ \nu$ (left plot) and $W^- \rightarrow e^- \bar{\nu}$ as functions of p_T . The data has been obtained for GRSV standard, GRSV valence [45], DSSV [14], and DNS [47] using a maximal and minimal sea polarization scenario in RHICBOS [58] for 300 pb^{-1} (full symbols) and 70 pb^{-1} (open symbols) assuming 70% beam polarization.

Forward $W \rightarrow \mu$ channel



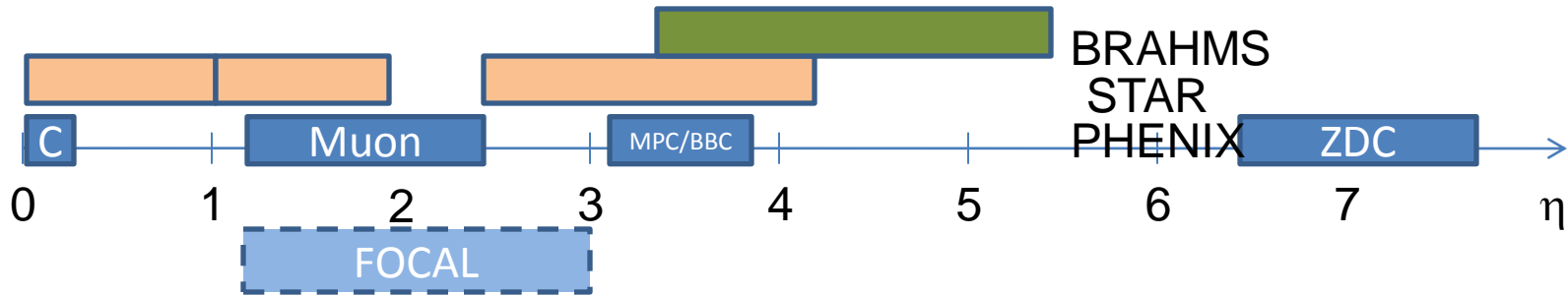
300/pb
1300/pb



It's more sensitive to d-bar distribution.
The high momentum μ trigger will
be ready by 2010.

What's next in transverse spin structure?

It looks forward is the key



Muon arm, MPC

FOCAL (tracking calorimeter)

Transversity x interference fragmentation function (IFF),
Single spin asymmetry of vector meson

Drell-Yan, gamma-jet

Predictions in the transverse spin



There is a prediction based on a solid theory background.

—**Sivers effect in Drell-Yan process (PLB536,43,... , arXiv:0901.3078)**

$$f_{1T}^{\perp}(x, k_T, \zeta)|_{\text{DIS}} = -f_{1T}^{\perp}(x, k_T, \zeta)|_{\text{DY}} \quad \text{FSI vs. ISI}$$

A fundamental test of the QCD.

Direct photon (forward) + jet (mid-rapidity) :

The same trick with larger cross section. (PRL 99,212002)

FOCAL gamma + central arm jet ?

pi0 photon / direct photon separation

trigger

Jet reconstruction...

RHIC schedule related to spin

2009 PAC recommendation

Year	Likely beam	PHENIX upgrade	RHIC upgrade	Gain from RHIC upgrade	comments
FY10	AuAu				No spin data
FY11	AuAu low \sqrt{s} pp@500 UU	VTX mu trigger	9MHz cavity AGS tune jump Spin flipper	short vtx width \rightarrow L Polarization Rel. Lum. systematic	W, step 1,2 Low $x A_{LL}$
FY12	AuAu@200 pp@500	FVTX	Electron lens Pol source	store lifetime \rightarrow L Polarization	W, step 2,3 Low $x A_{LL}$
FY13	pp@200 AuAu	FOCAL?			pp ref for HI with new det. Transverse spin?

RHIC is also a heavy ion machine.

Summary



ΔG program

- More integrated luminosity and polarization ($\sim x100$ FOM) is required for the direct photon asymmetry.
- For the x dependence, we need probes beyond inclusive measurement. Or change the collision energy.



500GeV

Anti-quark flavor decomposition

- This year, we collected the first $\sqrt{s}=500\text{GeV}$ data.
- We will focus on this topic for the following few years.



Transverse spin structure

- Many results from RHIC remain unexplained.
- It seems there is a key in the forward region.
- We are trying to find a new signal.

It is important to collaborate with accelerator group (RHIC spin collaboration).

Other PHENIX talks

Prof. A.Deshpande (Session 9)
Dr. M. Kurosawa (Session 11)
Mr. K. Nakamura (Session 11)

Backup slides

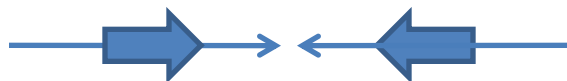
PHENIX datasets

Longitudinally Polarized Runs

The program for gluon polarization (Δg), anti-quark flavor \bar{s} spin ($\Delta u, \Delta d$)

Year	\sqrt{s} [GeV]	Recorded L	Pol [%]	FOM (P ⁴ L)
2003 (Run 3)	200	.35 pb ⁻¹	27	1.9 nb ⁻¹
2004 (Run 4)	200	.12 pb ⁻¹	40	3.1 nb ⁻¹
2005 (Run 5)	200	3.4 pb ⁻¹	49	200 nb ⁻¹
2006 (Run 6)	200	7.5 pb ⁻¹	57	790 nb ⁻¹
2006 (Run 6)	62.4	.08 pb ⁻¹ **	48	4.2 nb ⁻¹ **
2009 (Run9)	500	14 pb ⁻¹ **	35	210 nb ⁻¹ **
2009 (Run9)	200	16 pb ⁻¹ **	53	1260 nb ⁻¹ **

** initial estimate



(With the rotator on)

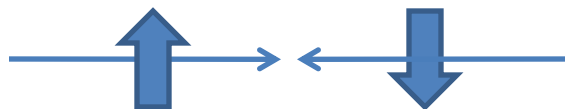
PHENIX datasets

Transversely Polarized Runs

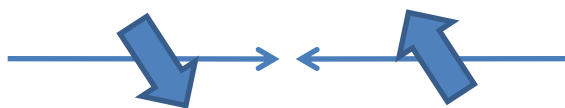
The program for transversity and orbital angular momentum.

Year	\sqrt{s} [GeV]	Recorded L	Pol [%]	FOM (P ² L)
2001 (Run 2)	200	.15 pb ⁻¹	15	3.4 nb ⁻¹
2005 (Run 5)	200	.16 pb ⁻¹	47	38 nb ⁻¹
2006 (Run 6)	200	2.7 pb ⁻¹	57	880 nb ⁻¹
2006 (Run 6)	62.4	.02 pb ⁻¹ **	48	4.6 nb ⁻¹ **
2008 (Run8)	200	5.2 pb ⁻¹ **	45	1100 nb ⁻¹ **

** initial estimate



Vertically polarized (the natural direction)



Radially polarized (with the rotator on)

Data flow

— Setup

spin rotator (confirmed by the local polarimeter)

Trigger threshold (as low as possible until hitting the DAQ rate limit)

— Data taking (fill ~8h)

Operate detectors (~20 subsystems)

Scaler counts of the luminosity monitor

Paused several times for RHIC polarimeter measurements.

Some special period (no magnetic field runs, vernier scans, etc.)

— Detector calibrations

Semi-online, offline

Data reconstruction and recalibration

— Analysis

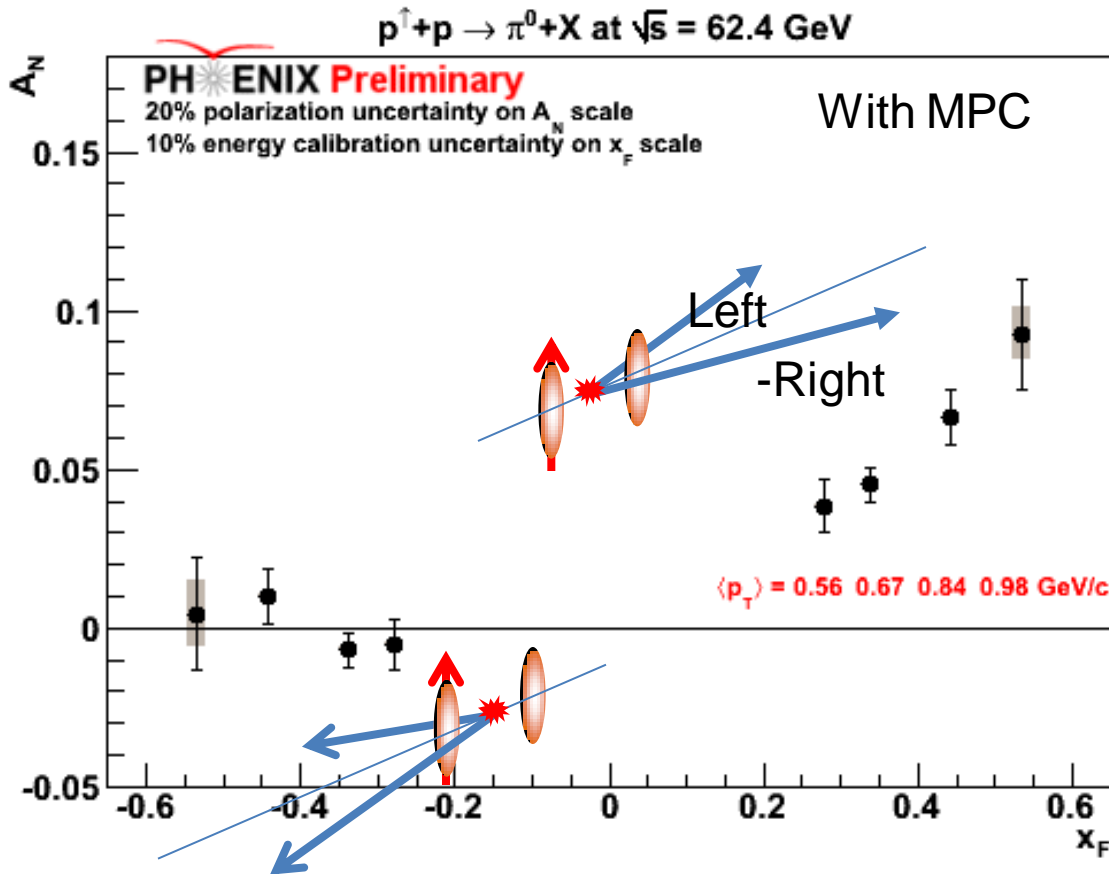
Signal cross section

(Signal+background) asymmetry is corrected by measured background asymmetry



Single spin asymmetry A_N

Naive pQCD (in a collinear picture) predicts $A_N \sim m_q/\sqrt{s} \sim 0$



However, large A_N observed in forward pions.
(also confirmed at PHENIX)



Proposed mechanisms

- Sivers
- Collins
- twist-3 process
- ...

Very hot topic recently

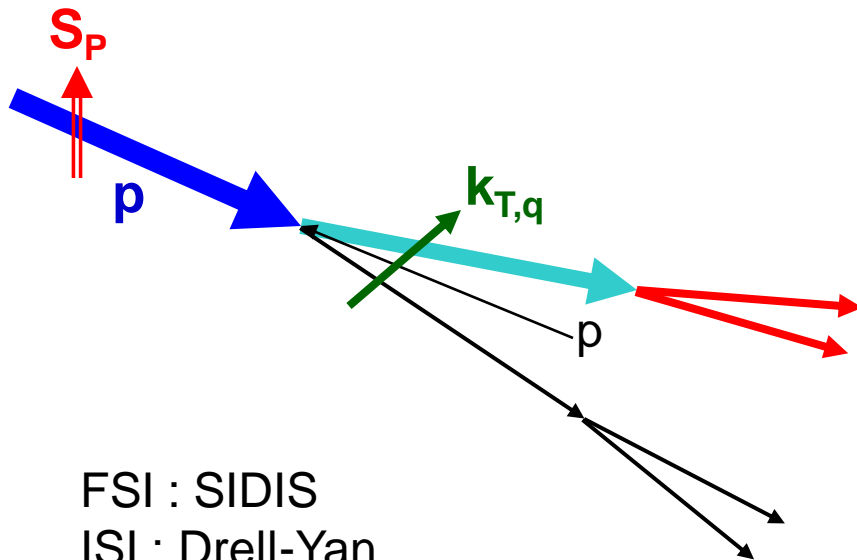
Possible mechanisms (ex.)

Sivers mechanism:

correlation between proton spin & parton k_T



quark, gluon motion in the polarized proton.

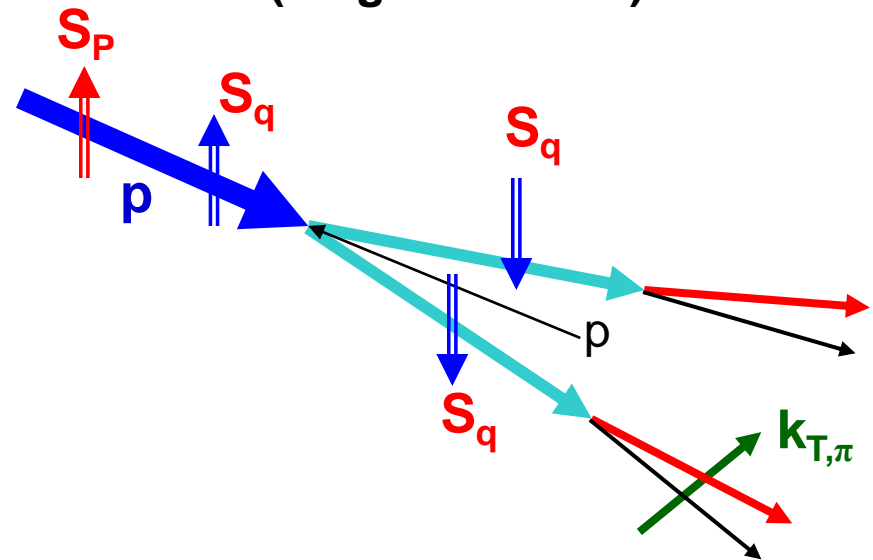


Collins mechanism:

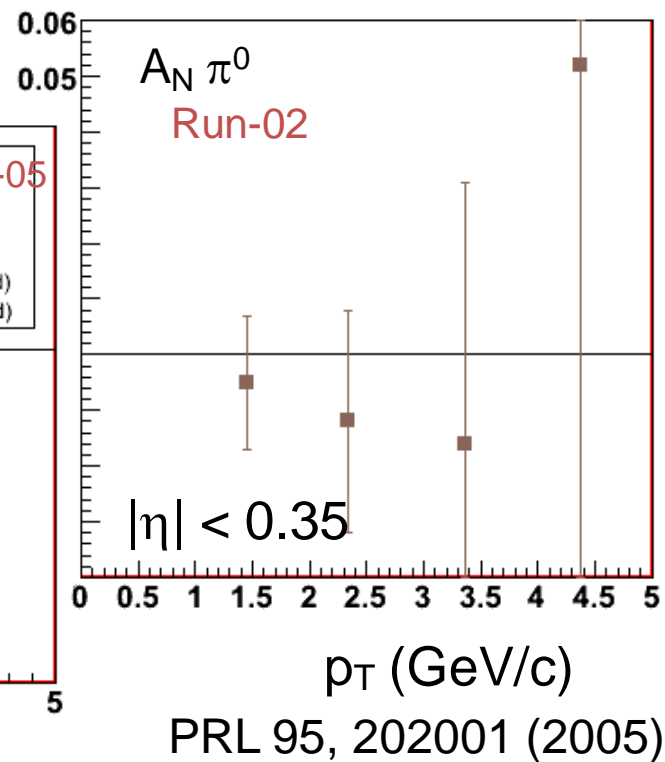
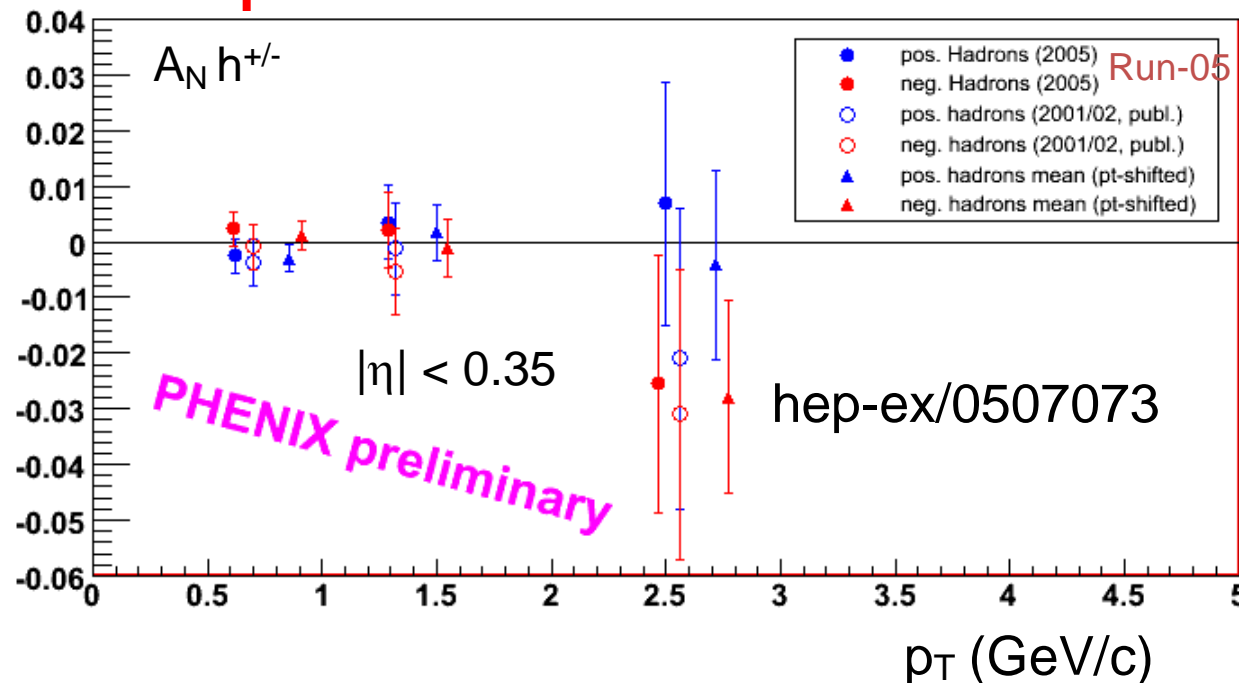
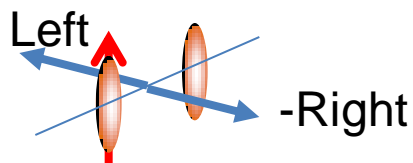
Transversity (quark polarization) × jet fragmentation asymmetry



quark polarization, needs an analyzer to be observed (no gluon effect)



Midrapidity hadron A_N



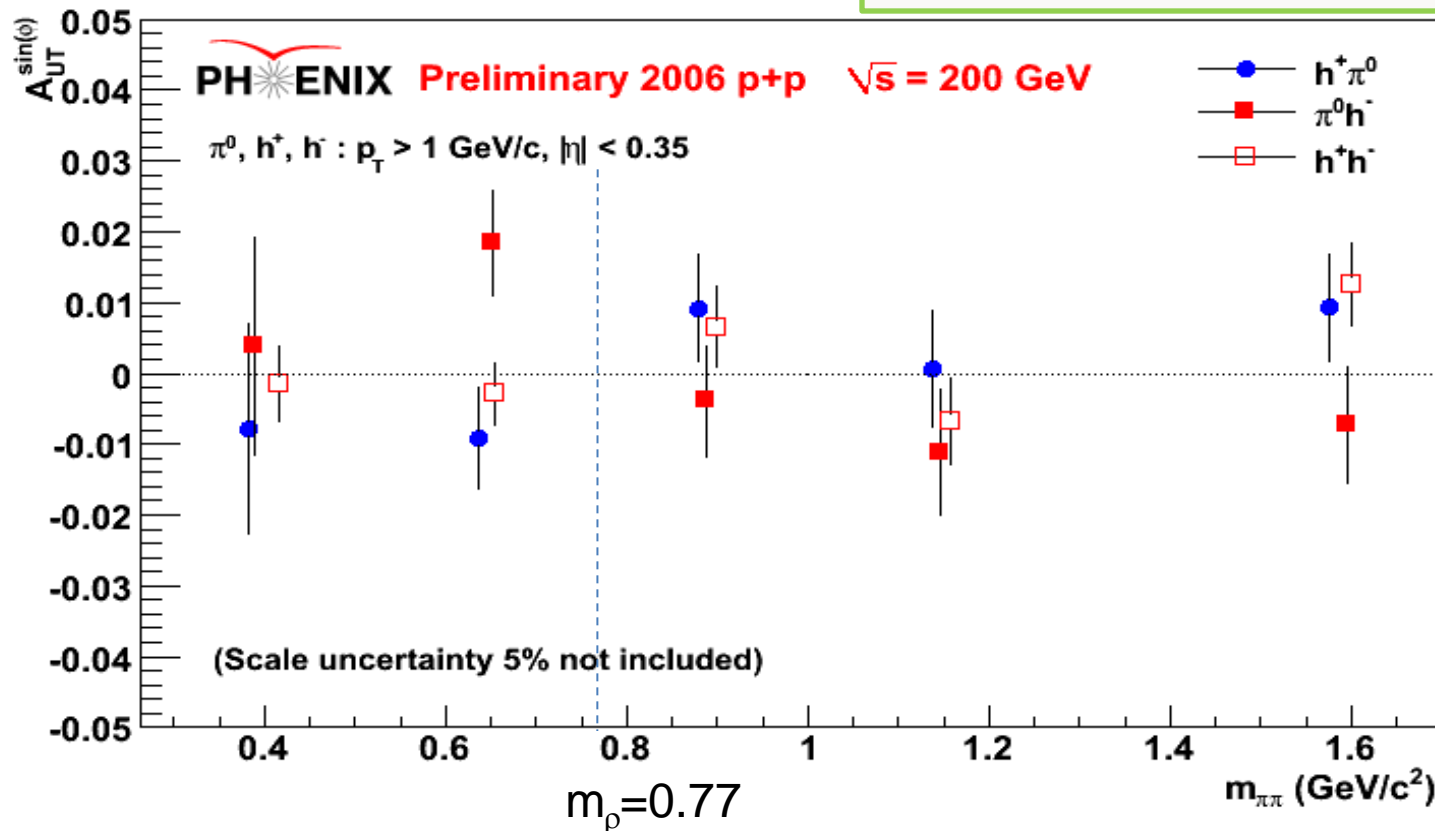
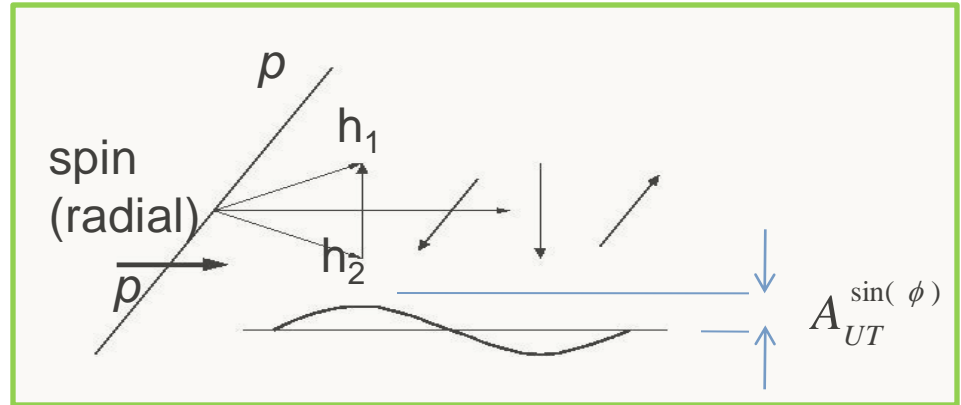
- A_N is zero within 1%
- It constrains Siverson distribution function for gluons not very large.

(Anselmino et al., PRD74, 094011 (2006))

- Updated π^0 analysis with $>10x$ smaller stat. error underway.

Interference FF as an analyzer

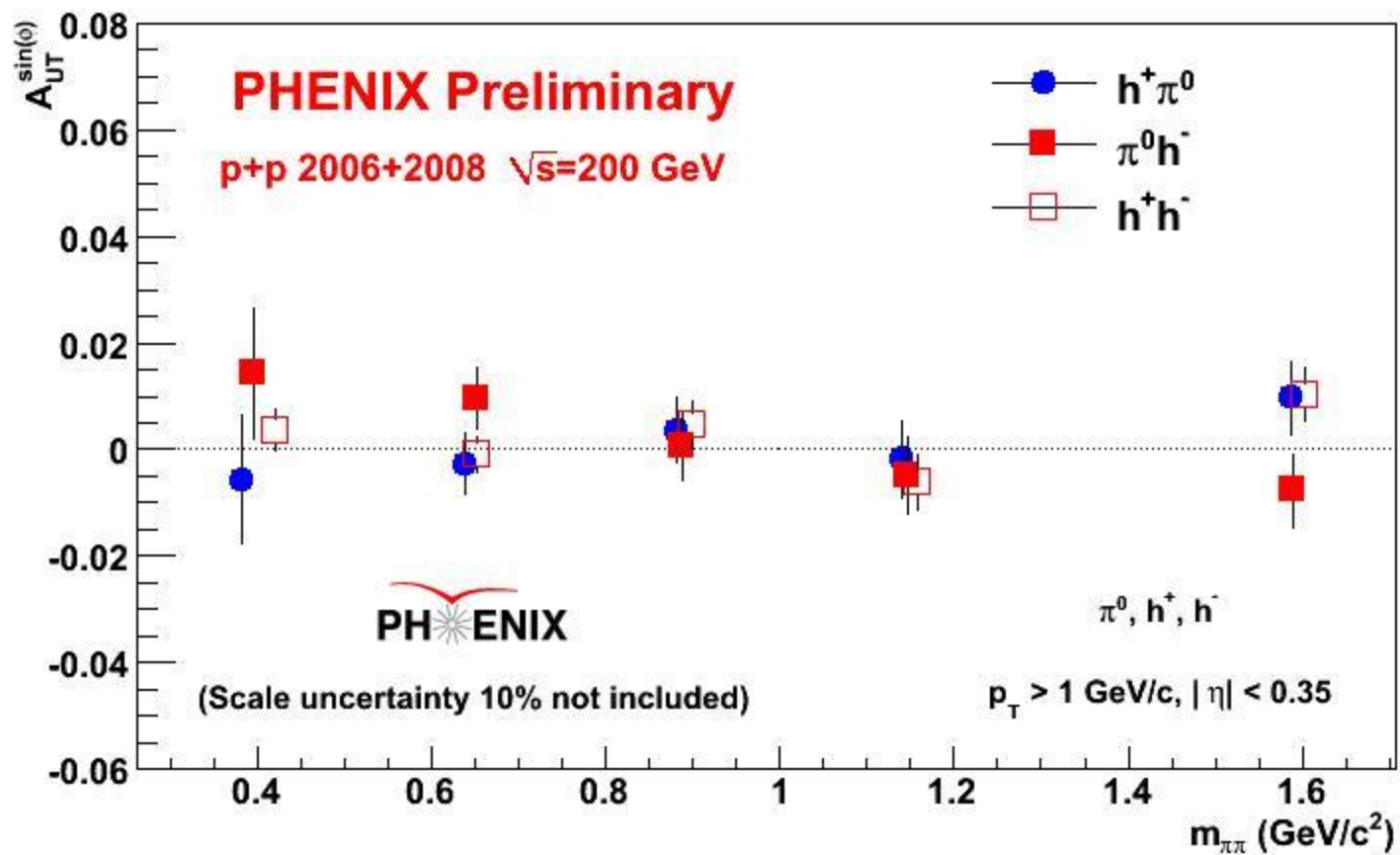
Transversity *IFF
2 hadrons in the central arm.



It's consistent with zero.

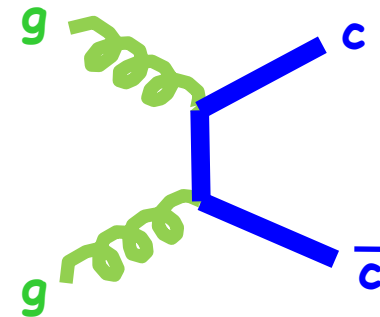
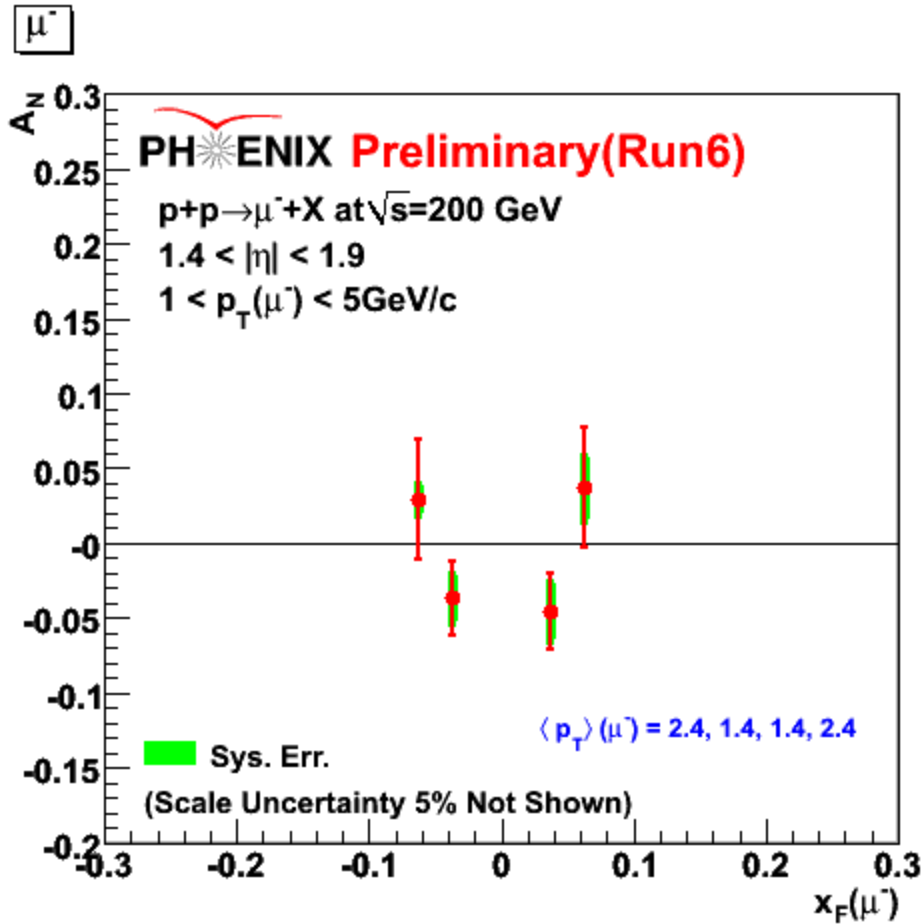
IFF from e+e collider data

The transversity will be constrained



open charm A_N

gluon fusion process
sensitive to the gluon Sivers effect.

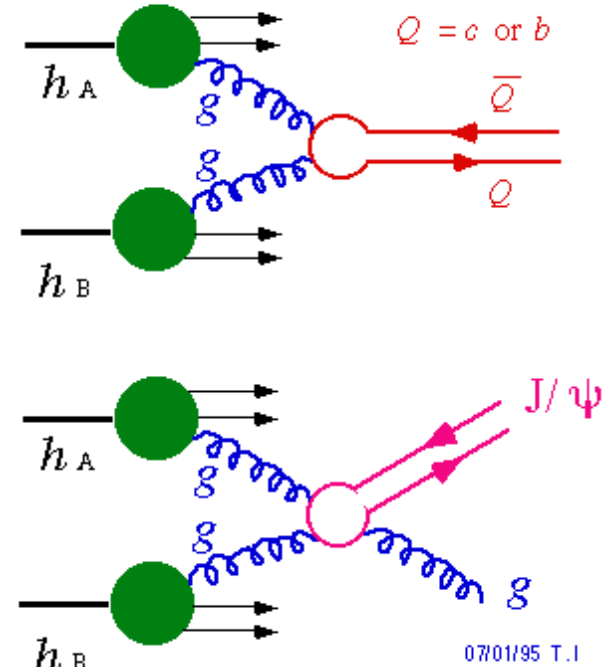
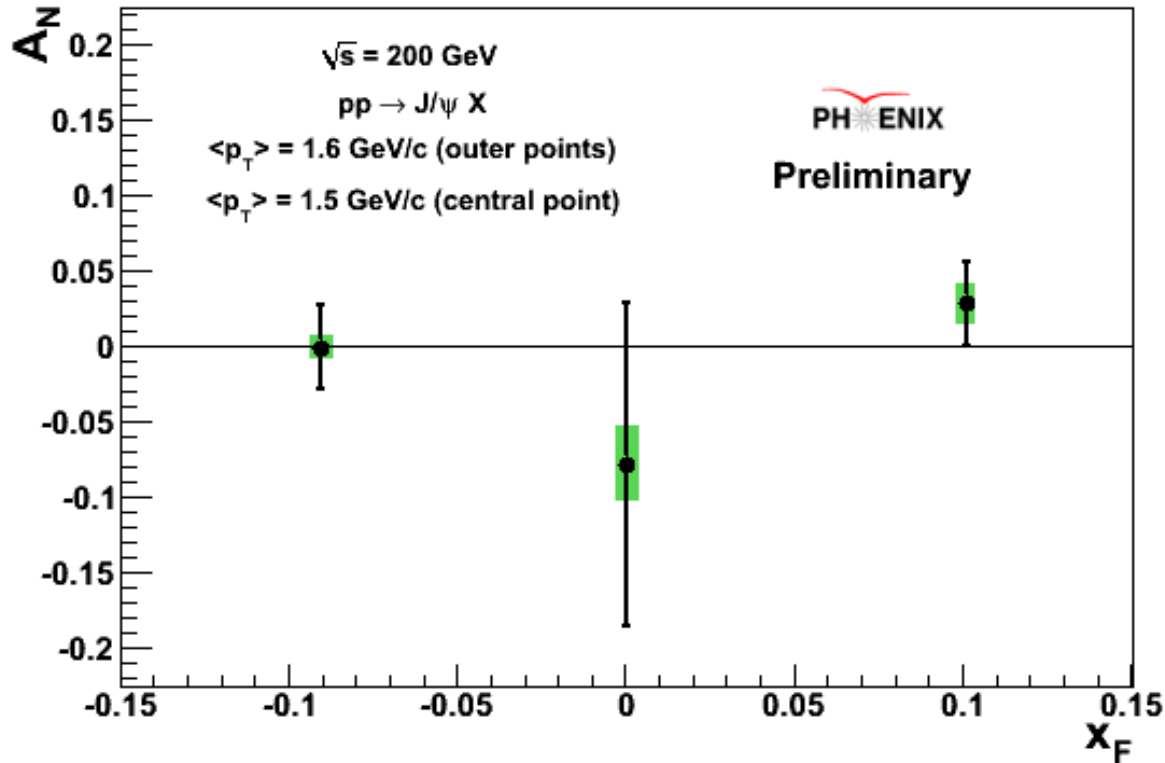


$c \rightarrow \mu, e$

It's consistent with zero.
 Consistent with the small gluon Sivers effect.
 An analysis on the electron channel is on going.

J/ψ A_N

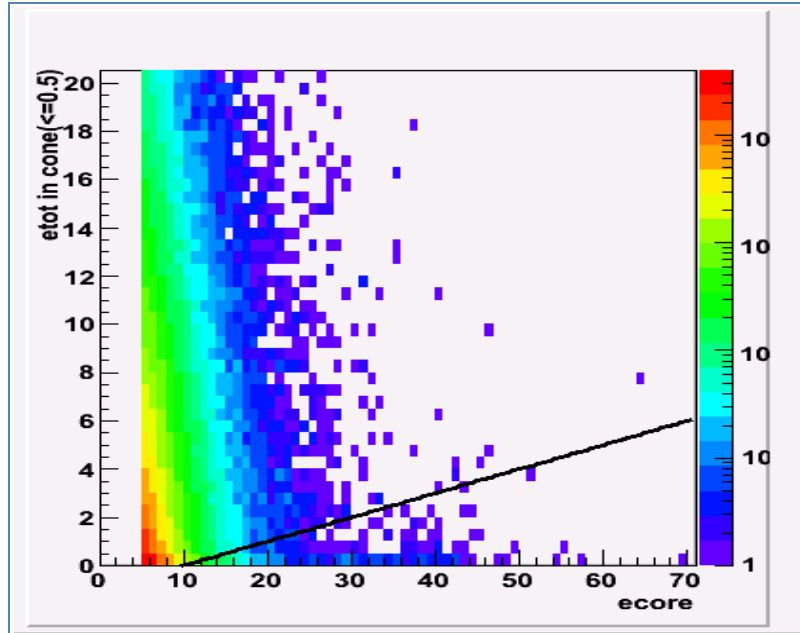
J/ψ 's are detected via di-lepton decay Gluon Fusion



It is also sensitive to the production mechanism (PRD 78,014024)
 The SSA survives in the color singlet model in $p+p$ collisions.

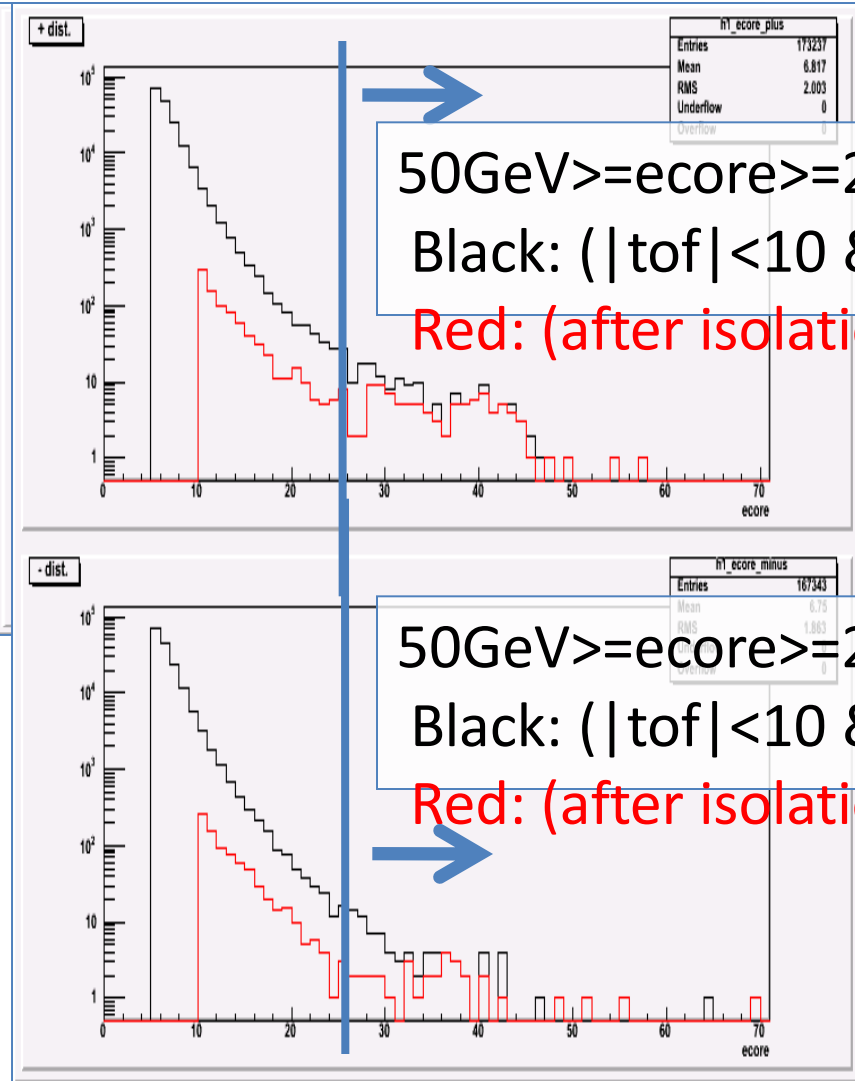
W→electron signal

Full statistics in Run9 ($\sim 10[\text{pb}^{-1}]$)

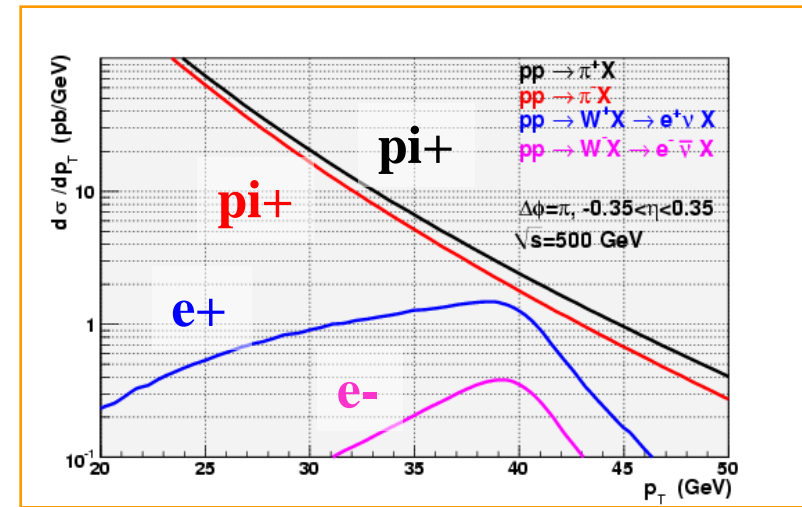
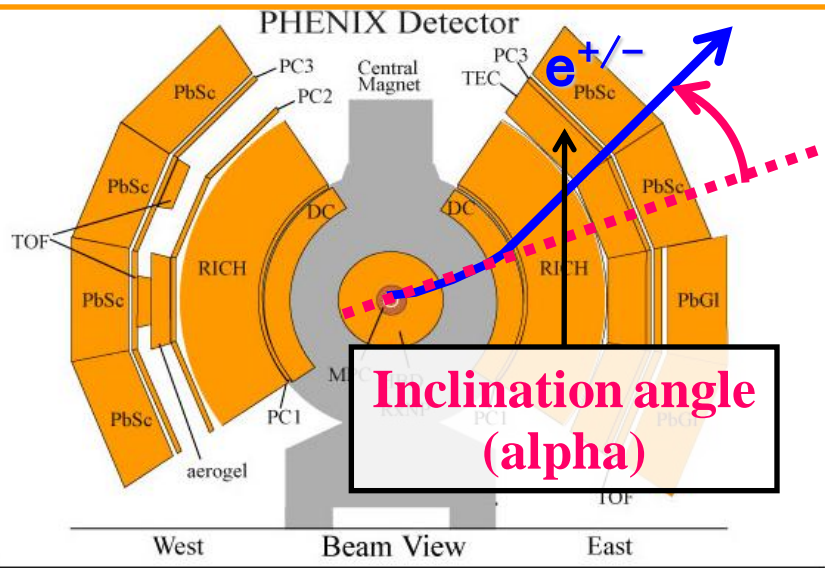


(total energy in the cone) vs energy

Cone size = 0.5,
Energy total =
EMCal energy + track momentum

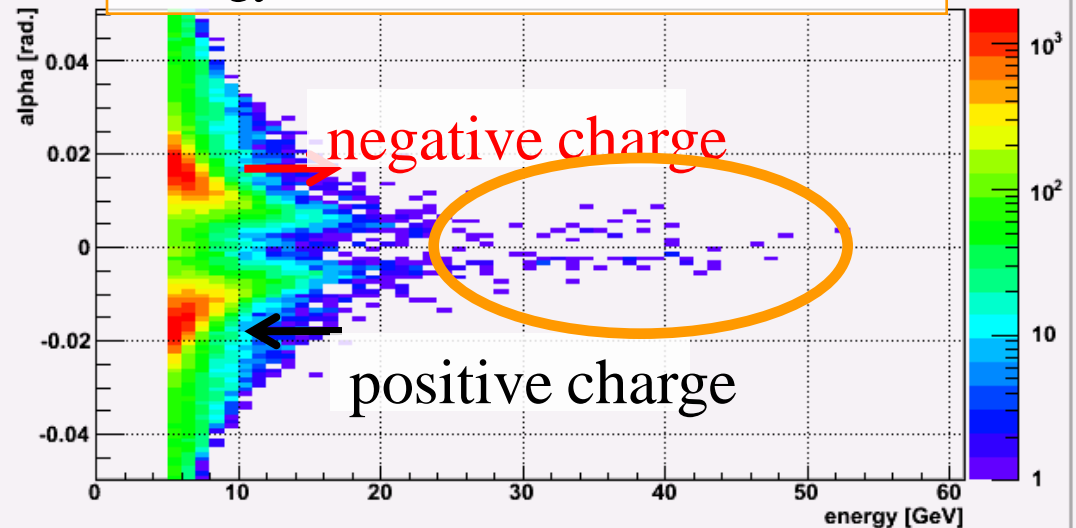


Charge separation



α [rad.] $\sim 0.1 / \text{mom}$ [GeV/c]
 “energy / mom < 3 ” cut applied

Energy v.s. Inclination of the track



Other probes

—Di-jet angle via 2 particle correlations : kT asymmetry

Central arm – Central arm

Central - Forward

Calculations based on observed Sivers effect in SIDIS.

STAR published a di-jet result (small $< \sim 1\%$) (PRL 99,142003)

A cancellation between (PRD 75, 075029)

ISI vs. FSI and

u-quark and d-quark \longrightarrow

There is a possibility to decompose by the charge of the leading hadron.

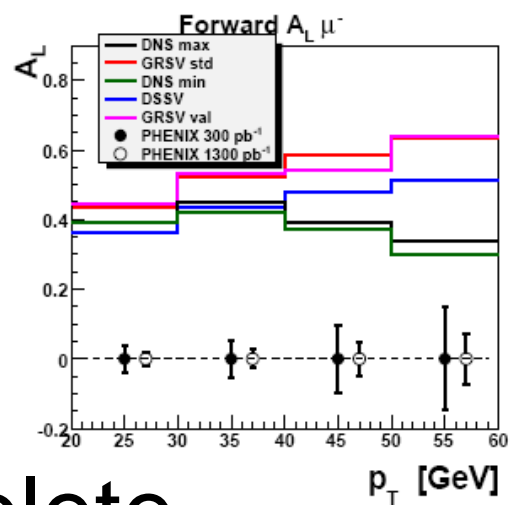
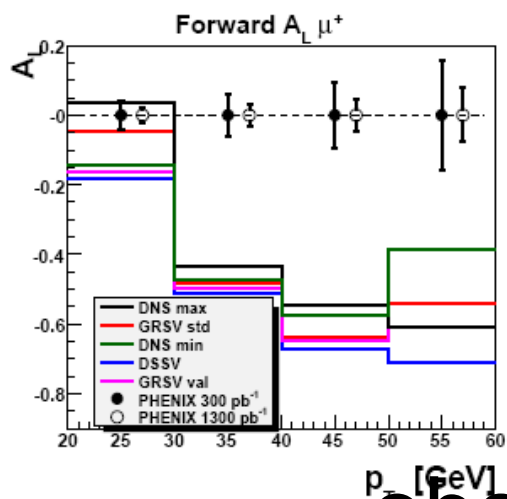
—Sivers effect in Drell-Yan process (PLB536,43,... , arXiv:0901.3078)

$$f_{1T}^{\perp}(x, k_T, \zeta)|_{\text{DIS}} = -f_{1T}^{\perp}(x, k_T, \zeta)|_{\text{DY}} \quad \text{FSI vs. ISI}$$

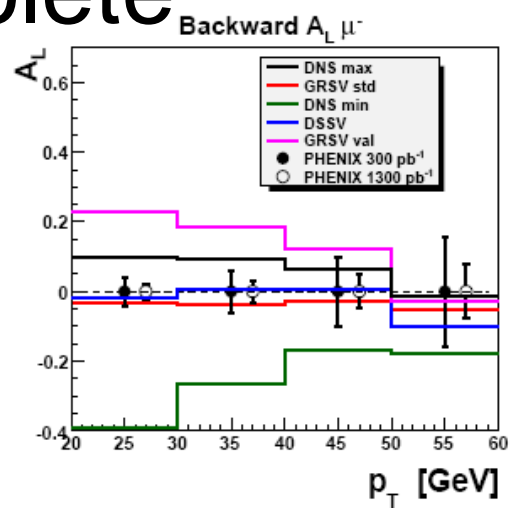
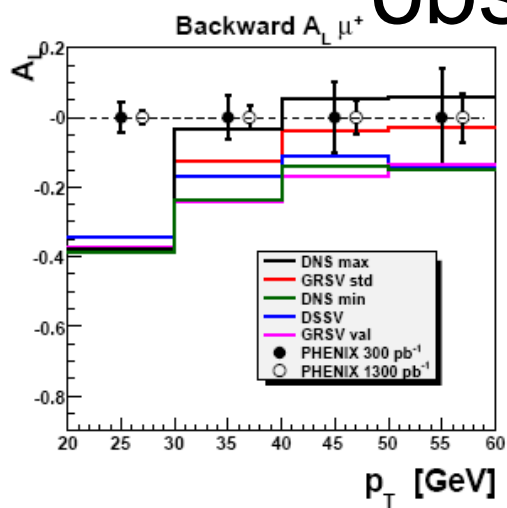
A fundamental test of the QCD.

Direct photon (forward) + jet (mid-rapidity) :

The same trick with larger cross section. (PRL 99,212002)

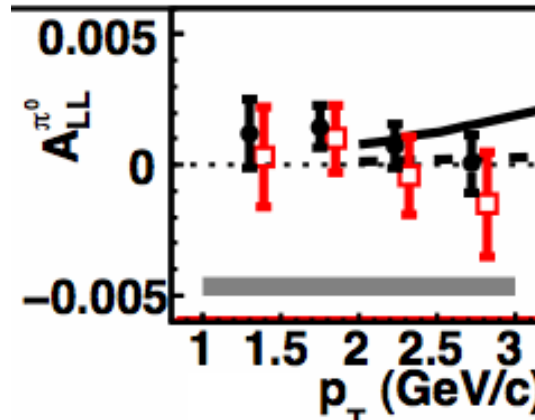
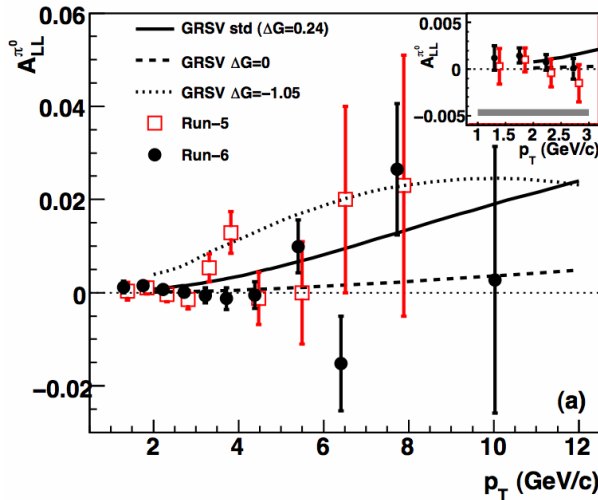
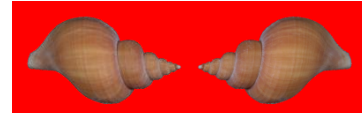


obsolete



The measurement is getting harder

Very small asymmetry



Systematic
uncertainty
~0.1%

Statistics limit from the experimental data acquisition.
Systematic uncertainty on the relative luminosity measurement.
(= relative A_{LL})